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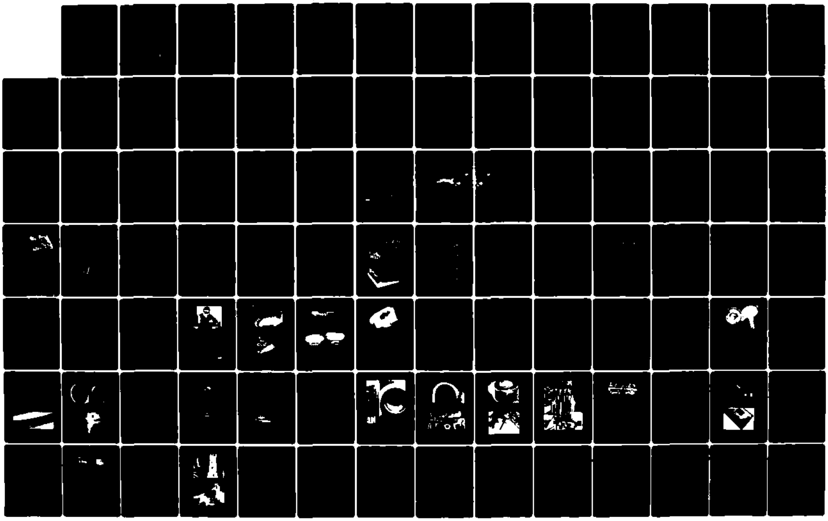

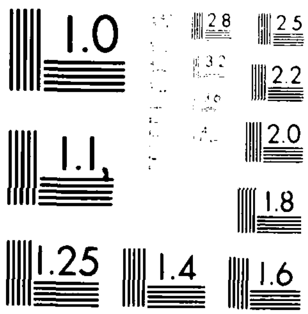

MICROCOPY RESOLUTION TEST CHART

DESERT TESTING OF MILITARY MATERIEL

Prepared for:

U.S. Army Yuma Proving Ground
Yuma, Arizona

by

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ABSTRACT

The regulatory controls for testing military materiel under adverse environmental conditions of the world deserts are delineated. The desert environment is described and specific characteristics of the major world deserts delineated. Adverse effects of the desert environment on military equipment and materials are discussed. The U.S. Army Yuma Proving Ground is discussed in terms of its facilities and capabilities for evaluating the suitability of military materiel for operation in analogous areas of the deserts of the World. Desert testing methodology for specific types of Army materiel is discussed in terms of development and execution of test plans.

I. INTRODUCTION

A. GENERAL

The U.S. Army has defined a desert as an area in which the seasonal or annual rainfall is less than the seasonal or annual evaporation rate.[1]* Meteorological conditions common to all desert regions are glaring sunlight, sudden and violent windstorms, and drastic changes in temperature. Further, "the most important deserts—politically and militarily – are the Sahara (which includes the Libyan and Nubian Deserts) in North Africa and the Arabian and Seistan Deserts in the Middle East. Also of importance is the Gobi Desert in Mongolia. These deserts are of importance because they separate two or more spheres of political and religious influence; they contain valuable mineral deposits; and they have strategic implications because of their location" (ibid).

Because military operations could occur in these areas and because the physical char... ristics of such regions could present adverse influences on military equipment and personnel, specific crite... have been promulgated in regulations and standards for guidance in the development and use of military ...uipment in the desert. Inasmuch as the developer is bound by the performance limits and constraints es... shed by these regulations, standards and specifications, equipment so designed must be evaluated again... limitations to ensure that it does perform as prescribed and thus have a high probability of successfu... eration in the expected environment.

The purpose of this manual is to provide the detailed background necessary for an understanding of the testing of military materiel in the desert environment. In so doing, however, only that information concerning the desert environment that is specifically pertinent to the operation, use or testing of military materiel items will be discussed. Bibliographic references will be made, where appropriate, to other sources of in-depth information on specific subjects, such as origin and development of worldwide deserts, detailed faunal and floral characteristics, geology, terrain, soil structure, and climate. Overall desert criteria will be discussed and desert "analogs" described with relation to testing.

B. REGULATIONS AND STANDARDS FOR ENVIRONMENTAL DESIGN

1. Pertinent Regulations and Standards

Recognizing the impact of adverse environmental conditions on the operation, transportation and storage of military equipment, the U.S. Army, in coordination with other branches of the Department of Defense and those of allied nations, has established specific regulations governing the design, development and evaluation of military equipment subject to exposure to such adverse conditions. These documents, Army Regulations (AR); interservice Military Standards (MIL-STD); and international agreements, QSTAG (Quadripartite—American-British-Canadian-Australian-New Zealand); and STANAG (NATO), provide specific definition of the environmental factors and control levels desired to be incorporated into materiel designed for worldwide use.**

*Superscript numerals indicate references at the end of this document.

**Equipment which is to be employed exclusively in a limited region should be designed to meet the specific adverse conditions of that region rather than the perhaps broader requirements established by these documents.

The follow [illegible] the effect of adverse environments on military equipment [illegible] that delineate broader aspects of materiel [illegible]

FM 31-25 — Desert Operations. [illegible] the conduct of troop operations in the desert. [illegible] but its discussion of desert characteristics is [illegible] effects of the desert on personnel and equipment and the [illegible] that must be considered.

AR 70-1 — Army Research, Development and Acquisition. This regulation establishes the processes for acquisition of Army [illegible] and responsibilities for each pertinent phase of the process. [illegible]

AR 70-10 — [illegible] and Development of Materiel. [illegible] defines the overall [illegible] testing and approval [illegible] extreme climatic testing [illegible] Test Program [illegible]

AR 70-15 [illegible] and the testing and approval of [illegible] types of testing, including environmental, [illegible]

AR 70-38 — Research and Development [illegible] and Evaluation of Materiel for Extreme Climate Conditions. This document [illegible] and storage of Army materiel under adverse environmental conditions that [illegible] throughout the world. It delineates four climatic design types relative to [illegible] for testing. It further defines its relationship to MIL-STD-210 [illegible] this section.

AR 71-3 — User Testing. [illegible] operational portion of the materiel development [illegible] Operational Tests" (OT) by organizational [illegible] Operational Test and Evaluation Agency (OTEA) [illegible] materiel, as designed by the developer. Development and M[illegible] Command [illegible] for operational climatic testing in "expected [illegible] the developer's tests (DT) for extreme climatic testing data.

AR 1000-1 — Basic Policies for System Acquisition. This regulation defines the basic development acquisition cycle in terms of not only the [illegible] design but also evaluation of its acceptability for all of the constraints of [illegible] energy conservation, and other such factors as a part of, or in addition to, [illegible]

MIL-STD-210C — Military Standard, Climatic Extremes for Military Equipment. This interservice standard establishes uniform [illegible] climatic design criteria for all military materiel intended for worldwide use and for testing of such materiel. It establishes sets of climatic extreme design conditions for land, sea and air operation and separately for storage on land and sea. A policy of survival for "percentage encounter" of extreme [illegible] "withstanding" (storage) climatic conditions is delineated. This will be further discussed in relation to AR 70-38.

MIL-STD-810 — Environmental Test Methods. This standard provides detailed guidance for environmental testing performed primarily under chamber or laboratory simulation conditions. It delineates the specific tests to be conducted and defines the data to be collected, including the accuracy of measurements to be obtained. Except peripherally, it does not provide specific guidance for testing in natural environments.

QSTAG 360 — Quadripartite (ABCA) Standardization Agreement, Climatic Environmental Conditions Affecting the Design of Military Materiel. This is an international statement of the probable extreme climatic conditions to be met by military equipment in ground storage, transit and operation. It is to be used for test planning. It sets out nine "Climatic Categories", delineating distinctive conditions observed in four types of world climates that may be encountered by military equipment (Antarctica excluded). It further provides guidance in evaluation of acceptability of materiel failures in accordance with an eight-level classification of failure covering four levels each of reversible and irreversible damage.

STANAG 2831 — NATO Standardization Agreement, Climatic Environment-Temperature and Humidity Limitations for Equipment used by NATO Armed Forces in a Ground Role. This agreement is essentially equivalent to the QSTAG 360 agreement. In effect, it extends those provisions to cover all NATO ground equipment. It provides maximum, minimum, and diurnal temperature and humidity limits for operation and storage of equipment in seven "Climatic Extreme" categories.

2. Relationship Between AR 70-38 and Other Standards and Agreements

There are two principal differences between AR 70-38, MIL-STD-210, and the other documents concerned with defining limitations of adverse environmental factors:

- MIL-STD-210 applies only to materiel designed for worldwide use. The other documents provide criteria for operation in more limited zonal regions by delineating climatic categories within the worldwide scope.

- AR 70-38 recognizes that "withstanding" (storage and transit) environments may induce more severe conditions (higher temperatures) than occur naturally. The other documents do not include this more stringent limitation, although they prescribe extreme cold temperature categories not accepted in AR 70-38.

a. *One Percent Risk*

A policy designated as "one percent risk" is established in defining the limitations of the various environmental factors in MIL-STD-210. These are values of climatic elements that are exceeded not more than one percent of the time of the most extreme month in an average year at the most severe location for that element. (For low temperatures, the level selected was for 20 percent of the time and for rainfall, 0.5 percent.) The probability that materiel will be exposed to a specific environmental element extreme cannot be accurately computed; however, these values, known as "one percent design values", are considered to be very conservative.[5, p A1]

Because of the stringency of these limitations imposed for worldwide use, where certain of the climatic elements achieve their one percent design values in very limited locations, some modification of this policy is recognized in AR 70-38 and the international agreements. Hence, the climatic domain of the world is divided, on the basis of temperatures, into zones (four for AR 70-38 and three for QSTAG 360 and

STANAG 2831). These are further subdivided with respect to precipitation and humidity. In effect, this approach allows the design of equipment for use at one or the other of the extremes, which establishes it as a unique design situation. Other materiel, not expected to be employed under that condition, would thus be freed of the necessity for accommodating that limitation to the extreme degree otherwise called for.

b. *Comparative Provisions*

Tables I-1, I-2, and I-3 show the comparative values for these climatic categories, and Table I-4 summarizes the provisions of MIL-STD-210 and includes environmental factors not treated in the other documents. There are some differences in values for the various climatic elements among the first three tables, but these are essentially negligible, generally arising from conversions between USA and metric measurement standards. QSTAG 360 and STANAG 2831 are practically identical except for the omission of the wet/warm and wet/hot (B1 and B2) categories by STANAG 2831. AR 70-38, however, omits the "extreme

TABLE I-1. SUMMARY OF AR 70-38 TEMPERATURE, SOLAR RADIATION, AND RELATIVE HUMIDITY DAILY CYCLES

Climatic Design Type	Daily Cycle (QSTAG 360 Equivalents)*	Operational Conditions: Ambient Air Temperature °F (°C)	Operational Conditions: Solar Radiation Btu/ft²/hr (W/m²)	Operational Conditions: Ambient Relative Humidity %	Storage and Transit Conditions: Induced Air Temperature °F (°C)	Storage and Transit Conditions: Induced Relative Humidity %
Hot	Hot Dry (A1)	90 to 120 (32 to 49)	0 to 355 (0 to 1120)	3 to 8	91 to 16[illegible] (33 to [illegible])	[illegible]
	Hot Humid (B3)	88 to 105 (31 to 41)	0 to 343 (0 to 1080)	59 to 88	91 to 160 (33 to 71)	14 to 80
Basic	Constant High Humidity (B1)	Nearly Constant 75 (24)	Negligible	95 to 100	Nearly Constant 80 (27)	95 to 100
	Variable High Humidity (B2)	78 to 95 (26 to 35)	0 to 307 (0 to 970)	74 to 100	86 to 145 (30 to 63)	19 to 75
	Basic Hot (A2)	86 to 110 (30 to 43)	0 to 355 (0 to 1120)	14 to 44	86 to 145 (30 to 63)	5 to 44
	Basic Cold (C1)	−5 to −25 (−21 to −32)	Negligible	Tending toward saturation	−13 to −28 (−25 to −33)	Tending toward saturation
Cold	Cold (C2)	−35 to −50 (−37 to −46)	Negligible	Tending toward saturation	−35 to −50 (−37 to −46)	Tending toward saturation
Severe Cold	Severe Cold (C3)	−60 (Cold soak) (−51)	Negligible	Tending toward saturation	−60 (−51)	Tending toward saturation

*Designations in parentheses refer to corresponding climatic categories in Quadripartite Standardization Agreement 360 *Climatic Environmental Conditions Affecting the Design of Military Materiel*. Two of the QSTAG 360 categories (C0 and C4) are not used by the United States.

NOTE: The numbers shown for the climatic elements represent only the upper and lower limits of the cycles that typify days during which the extremes occur, e.g., for the Hot Dry cycle, 120° F is the maximum daytime temperature and 90° F is the minimum nighttime (or early morning) temperature.

TABLE I-2. SUMMARY OF QSTAG 360 TEMPERATURE, SOLAR RADIATION AND RELATIVE HUMIDITY EXTREMES FOR CONSIDERATION IN DESIGN OF MILITARY EQUIPMENT CELCIUS SCALE

TYPE OF CLIMATE	CLIMATIC CATEGORY	CLIMATIC CONDITIONS: OPERATIONAL CONDITIONS: TEMPERATURE °C	SOLAR RADIATION (W/m²)	RELATIVE HUMIDITY %	STORAGE AND TRANSIT EXTREME CONDITIONS: TEMPERATURE	RELATIVE HUMIDITY %	OTHER FACTORS
A High Temperature Low Humidity	A1 Hot Dry	32 to 52	[illegible]	[illegible] 20	32 [illegible]	[illegible] 5	Rain, Wind, Atmospheric Pressure, Sand, Dust
	A2 Intermediate Hot Dry	21 to 44	[illegible]	[illegible] 85	21 [illegible] 63	[illegible] 50	Rain, Wind, Atmospheric Pressure, Sand, Dust
B High Temperature High Humidity	B1	24	Negligible	[illegible]	[illegible]	95 [illegible]	Rain, Wind, Atmospheric Pressure
	B2 Wet Hot	26 [illegible]	[illegible]	[illegible]	32 [illegible]	[illegible] 85	Rain, Wind, Atmospheric Pressure, Sand, Dust
	B3 Humid Hot Coastal Desert	[illegible] 38	[illegible]	[illegible]	32 [illegible]	[illegible] 85	Rain, Wind, Atmospheric Pressure
C Low Temperature See Note 1	C1 Intermediate Cold	21 [illegible] 32	Negligible	Tending toward saturation	23 [illegible] 44	Tending toward saturation	Rain, Snow Load, Wind, Atmospheric Pressure, Snow, Sand, Dust
	C2 Cold	32 to 46	Negligible	Tending toward saturation	32 [illegible] 46	Tending toward saturation	Snow Load, Wind, Atmospheric Pressure, Snow, Sand, Dust
	C3 Severe Cold See Note 2	46 to 51	Negligible	Tending toward saturation	46 [illegible]	Tending toward saturation	Snow Load, Wind, Atmospheric Pressure, Snow, Sand, Dust
	C4 Extreme Cold	51 to 57	Negligible	Tending toward saturation	[illegible]	Tending toward saturation	Snow Load, Wind, Atmospheric Pressure, Snow, Sand, Dust

NOTE 1 In the design of equipment for sole use by the Australian Army, Australia will consider this type of climate as having no categories of sub-division, no diurnal cycles, and a single temperature of -15°C for operational temperature and -18°C for storage temperature; solar radiation will be considered as negligible and relative humidity as tending towards saturation.

2 The U.S. Army does not use this category.

cold" (C4) category of -60° to -70°F (-51° to -57°C)* and considers the "severe cold" (C3) category of -60°F (-51°C) only for cold soaking during operating conditions and for transit and storage (withstanding).

3. Unique Provisions of AR 70-38

AR 70-38 includes a statement identifying and classifying materiel failures, as related to adverse climatic factors, as "reversible" and "irreversible," with respect to whether normal operation is regained

*In this document all measurement conversion will be to the same order of precision, unless otherwise stated.

TABLE I-3. TEMPERATURE AND HUMIDITY LIMITATIONS FOR EQUIPMENT USED BY NATO ARMED FORCES OPERATING IN A GROUND FORCE-STANAG 2831 OPERATING AND STORAGE LIMITS

		OPERATING						STORAGE			
Climatic Limits	Designation of Climatic Extremes Categories	Extreme Temperature		Relative Humidity %		Maximum Solar Radiation		Extreme Temperature		Relative Humidity %	
		F	C	Accompanying max. temp. of daily cycle	Accompanying min. temp. of daily cycle	[illegible]	[illegible]	F	C	Accompanying max. temp. of daily cycle	Accompanying min. temp. of daily cycle
Basic Operating Limits A1	Hot Dry	125	52	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50
C1	Intermediate Cold	25	32	Tending towards saturation				30	34	Tending towards saturation	
B3	Humid Hot Coastal Desert	100	38	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	85
Temperate only Operating Limits A2	Intermediate Hot Dry	110	44	20	[illegible]	[illegible]	[illegible]	[illegible]	63	5	50
C1	Intermediate Cold	25	32	Tending towards saturation				[illegible]	34	Tending towards saturation	
Colder Operating Limits C2	Cold	50	46	Tending towards saturation				[illegible]	46	Tending towards saturation	
C3	Severe cold	60	51	Tending towards saturation				[illegible]	51	Tending towards saturation	
C3	Extreme cold	70	57	Tending towards saturation				[illegible]	57	Tending towards saturation	

when the effect of the adverse environmental condition is removed. QSTAG 360 and STANAG 2831 categorize such failures further into eight types, with respect to the relative degradation caused by environmental conditions in excess of those for which the materiel was designed, as follows:

a. *Reversible Failures*

- Type A — The equipment may continue to function but with reduced performance, returning to normal efficiency after the more extreme conditions cease. It remains safe throughout.

- Type B — The equipment may cease to function altogether but recover normal efficiency after the more extreme conditions cease. It remains safe throughout.

- Type C — The equipment continues to function but with reduced performance during the extreme conditions and, in addition, becomes dangerous to life or to some other essential equipment in the vicinity. When the more extreme conditions cease, the equipment will return to normal efficiency provided the danger did not eventuate.

b. *Irreversible Failures*

- Type D — During extreme conditions, the equipment ceases to function and endangers life or other adjacent, essential materiel. It returns to normal, safe performance when the extreme conditions have abated, if the danger has not ensued.

- Type E — The equipment may continue to function with reduced performance but after the more extreme conditions cease—never returns to normal efficiency. It remains safe throughout.

TABLE I-4. ENVIRONMENTAL FACTOR LIMITS FOR GROUND EQUIPMENT AS DEFINED BY MIL-STD-210[8]

ENVIRONMENTAL FACTOR	HIGHEST	LOWEST	OPERATION	WITHSTANDING EDE*, yrs:	2	5	
High Temperature °F (°C)	136 (58)		1% 120 (49) 5% 115 (46) 10% 113 (45)	Temp.:	128 (53)	130 (54)	1
Low Temperature °F (°C)		-90 (-68)	1% -78 (-61) 5% -70 (-57) 10% -65 (-54) 20% -60 (-51) 50% -50 (-46)	Temp.:	-86 (-66°)	-89 (-67°)	-[illegible]
High Absolute Humidity Temp, °F (°C)	35×10^3 95 (34) dew pt		1% 30×10^3 ppm, 88 (31°) dp (30 day periods - variable) 5% 28×10^3 ppm, 86 (30) dp during day 10% 26×10^3 ppm, 84 (29) dp 20% 25×10^3 ppm 83 (28) dp			NA	
Low Absolute Humidity Temp, °F (°C)		2.05 ppm -91 (-68) frost point	5.24 ppm -79 (-62)	ppm: frost point:	2.82 -87 (-66°)	2.22 -90 (-68)	 -[illegible]
High Relative Humidity, Temp, °F (°C)	100% 84 (29)		100% 78 (26) to 74% 95 (35)		100% 75 (24) to 95% 75 (24)		
Low Relative Humidity, Temp, °F (°C) (°C)		2% 110 (43)	3% 120 (49)	temp at 3% RH	128 (53)	130 (54)	1
					Withstanding for wind gust speeds, [illegible]		
Wind Speed fps (mps)	312 (95)		73 (22), 1% risk	 SHD**, ft (m)	105 (32) ≤2 (.61)	100 (30) 5 (1.5)	
Rain Rate in./hr (cm/hr)	1.23 (31.2)		0.0315 (0.80), 0.5% extreme	for 1 hr.[1] for 12 hr.[2] for 24 hr.[3]	4.0 0.9 (2.3) 0.6 (1.5)	4.7 (12) 1.1 (3.0) 0.7 (1.8)	

*EDE - Expected duration of exposure

**SHD - Shortest horizontal dimension of test object

(1,2,3) Wind speed at height of 10 ft., fps (mps): (1) 110 (33), (2) 84 (26), (3) 68 (21)

ENTAL FACTOR LIMITS FOR GROUND EQUIPMENT AS DEFINED BY MIL-STD-210[8]

OPERATION		WITHSTANDING					
	EDE*, yrs:	2	5	10	25		
1% 120 (49) 5% 115 (46) 10% 113 (45)	Temp.:	128 (53)	130 (54)	131 (55)	133 (56)		
1% 78 (61) 5% -70 (57) 10% -65 (54) 20% 60 (51) 50% 50 (46)	Temp.:	-86 (-66°)	-89 (-67°)	-92 (-69)	-95 (71)		
1% 30 x 10³ ppm, 88 (31°) dp (30 day periods variable) 5% 28 x 10³ ppm, 86 (30) dp during day 10% 26 x 10³ ppm, 84 (29) dp 20% 25 x 10³ ppm 83 (28) dp		NA					
5 24 ppm 79 (62)	ppm: frost point:	2.82 -87 (-66°)	2.22 -90 (-68)	1 74 -93 (-70)	1.36 -96 (-71)		
100% 78 (26) to 74% 95 (35)		100% 75 (24) to 95% 75 (24)					
3% 120 (49)	temp at 3% RH	128 (53)	130 (54)	131 (55)	133 (56)		
		Withstanding for wind gust speeds, not years					
73 (22), 1% risk		105 (32)	100 (30)	95 (29)	90 (27)	84 (26)	81 (25)
	SHD**, ft (m)	≤2 (.61)	5 (1.5)	10 (3.0)	25 (7.6)	50 (15)	100 (30)
0.0315 (0.80), 0.5% extreme	for 1 hr.[1]	4.0	4.7 (12)	5.2 (13)	5.8 (15)		
	for 12 hr.[2]	0.9 (2.3)	1.1 (3.0)	1 2 (3 0)	1 3 (3 3)		
	for 24 hr.[3]	0.6 (1.5)	0.7 (1.8)	0.7 (1.8)	0.8 (2 0)		

), (3) 68 (21)

TABLE I-4. ENVIRONMENTAL FACTOR LIMITS FOR GROUND EQUIPMENT AS DEFINED BY MIL-STD-210 (cont'd)

ENVIRONMENTAL FACTOR	HIGHEST	LOWEST	OPERATION	WITHSTANDING EDE*, yrs:	2	5	10
Hail Size dia, in. (mm)	516 (142) .001% extreme 2 (50) .01% extreme 0.8 (20)		None	Dia.	2.6 (70)	3.1 (80)	3.5
High Press. in Hg. (mb)	31.89 (1080)		Highest			Highest	
Low Press. in Hg (mb)	14.8 (503)		1% 15 (508) 5% 15.2 (514) 10% 15.4 (520) 20% 15.6 (527)			14.8 (503) Highest	
High Density lb/ft^3 (kg/m^3) at °F (°C)	0.111 (1.78) -90 (-68)		0.107 (1.72) -78 (-61)			NA	
Low Density lb/ft^3 (kg/m^3) at 15000' (4.57 km elev.)			0.0441 (0.707) at 57 (17)			NA	
Ozone, lb/ft^3 (μg/m^3)	203 x 10^8 (325)		1.37 x 10^8 (220)			NA	
Sand & Dust lb/ft^3 (g/m^3)	3.75 x 10^4 (6) (<74 μm dia)		near aircraft 1.32 x 10^4 (2.19) <500 μm dia near vehicles 6.61 x 10^5 (1.06) w/50 fps (18 mps) wind at 10 ft (3m) ht/< 1000 μm dia natural conditions 1.10 x 10^5 (0.177) w/50 fps (18 mps) wind at 10 ft (3 m) ht/< 150 μm dia			NA	

TABLE I-4. ENVIRONMENTAL FACTOR LIMITS FOR
UND EQUIPMENT AS DEFINED BY MIL-STD-210 (cont'd)

OPERATION	WITHSTANDING EDE*, yrs:	2	5	10	25
None	Dia.	2.6 (70)	3.1 (80)	3.5 (90)	4 (100)
Highest			Highest		
1% 15 (508) 5% 15.2 (514) 10% 15.4 (520) 20% 15.6 (527)			14.8 (503) Highest		
0.107 (1.72) -78 (-61)			NA		
0.0441 (0.707) at 57 (17)			NA		
1.37 x 10^{8} (220)			NA		
near aircraft 1.32 x 10^{4} (2.19) /<500 μ m dia			NA		
near vehicles 6.61 x 10^{5} (1.06) w/50 fps (18 mps) wind at 10 ft (3m) ht/< 1000 μm dia					
natural conditions 1.10 x 10^{5} (0.177) w/50 fps (18 mps) wind at 10 ft (3 m) ht/< 150 μm dia					

- Type F — The equipment may cease to function altogether, having suffered complete and permanent damage from the extreme conditions. It remains safe throughout.

- Type G — The equipment functions with reduced performance and, in addition, becomes dangerous to life or to some other essential equipment in the vicinity, this danger continuing for a long time (perhaps indefinitely) after the adverse conditions have abated.

- Type H — The equipment ceases to function and does not recover and, in addition, becomes dangerous to life or other essential materiel in the vicinity, this danger continuing for a long time (perhaps indefinitely) after the adverse conditions have abated.

c. *Other Provisions of AR 70-38*

- Rain

Operational rate: 0.03 in./min. (0.80 mm/min.)
0.07 in./min. (1.80 mm/min.) for missiles and aircraft

Nominal drop size:

Diam. (mm)	Number/m^3
0.5-1.4	2626
1.5-2.4	343
2.5-3.4	45
3.5-4.4	6
4.5-5.4	1
5.5-6.4	1

[Accompanying wind velocity, intermittent, 60 fps (18 mps)]

- Snow

Snowfall rate: — max. 3 in./hr (76 mm/hr)

Crystal size: — range 0.05-20 mm (.001-.8 in.)
— median 0.1-1.0 mm (.004-.04 in.)
— blowing snow: 0.02-0.4 mm (.001-.016 in.)

Horizontal Mass Flow in Air at 44 fps (13 mps) at the Following Heights Above the Ground Surface.
(temperature range 14°F to -4°F (-10°C to -20°C) down to -40°F (C)

Height Above Surface (ft)	(m)	Mass Flow (lb/ft² sec)	(g/m² sec)
33	10	$.45 \times 10^{-3}$	2.2
25	7.5	$.68 \times 10^{-3}$	3.3
16	5	$.82 \times 10^{-3}$	4.0
8.2	2.5	1.4×10^{-3}	6.9
3.3	1	3.3×10^{-3}	16
2.5	.75	4.5×10^{-3}	22
1.6	.5	6.6×10^{-3}	32
.8	.25	14×10^{-3}	66
.3	.1	41×10^{-3}	200
.2	.05	109×10^{-3}	530

Snowload

Portable equipment (tentage): 10 lb/ft² (49 Kg/m²); 20 in. (0.5 m) at 0.1 sp. gr.

Temporary equipment (rigid shelters) 20 lb/ft² (98 Kg/m²); 40 in. (1.02 m) at 0.1 sp. gr.

Semipermanent: 48 lb/ft² (235 Kg/m²): 96 in. (2.44 m) at 0.1 sp. gr.

- Icing

  Operational: 0.5 in. (13 mm) at 0.9 sp. gr

  Withstanding: see MIL-STD-210

- Hail

  Operational: up to 2 in. (51 mm) diameter

- Wind

  Operational. Same as MIL-STD-210 at 10 ft (3 m) height

  Steady 73 fps (22 mps)

  Gusts 95 fps (29 mps)

Multiplying factors for other elevations above surface:

Height (ft)	Height (m)	Steady	Gusts
5	1.5	0.917	0.946
10	3	1.000	1.000
20	6	1.090	1.057
30	9	1.147	1.092
40	12	1.189	1.117
50	15	1.222	1.137
75	23	1.286	1.175
100	30	1.334	1.202
200	61	1.454	1.271
300	91	1.530	1.313
400	122	1.586	1.343
500	152	1.631	1.368
1000	305	1.778	1.445

- Sand and Dust
  - Particle Size:
    - Range—0.1 to 1000 μm (3.94×10^{-6} to 3.94×10^{-2} in.)
    - Median—74 μm (2.9×10^{-3} in.)
  - Operational concentrations at 70° F (21° C) and less than 30% RH
    - Ground equipment in downwash of helicopters or aircraft (unpaved surfaces)—1.32×10^{-4} lb/ft^3 (2.19 gm/m^3
    - Equipment near operating surface vehicles 6.61×10^{-5} lb/ft^3 (1.06 gm/m^3) in winds 59 fps (18 mps) at 10 ft (3 m) height.
    - Equipment subject only to natural conditions 1.1×10^{-5} lb/ft^3 (0.177 gm/m^3) at winds 59 fps (18 mps) (particle size up to 150 μm (5.9×10^{-3} in.)

- Ozone Concentration
  - Operational: 1.37×10^{-8} lb/ft^3 (220 μg/m^3)

- Atmospheric Pressure
  - Operational High—1080 mb (31.89 in.)
  - Low—508 mb (15.0 in.) at 15,000 ft/(4,572 m)
  - Extreme Sea Level Low—877 mb (25.9 in.)

C. LIFE CYCLE OF MILITARY MATERIEL

The "Life-Cycle" of acquisition and use of the weapons and equipment (materiel) of the Army is usually depicted in a sequential process from procurement to issue to the operational arm or service.[12, para 1-3]

Where nonexpendable materiel is concerned, issue and operational use may include intermediate stages of field storage or maintenance and reissue before ultimate consumption or disposal, and operational use may include storage (stowage) and installation on vehicles, instrumentation vans; and artillery or missile launchers, i.e., transportation modes.

Throughout this sequence, adverse environmental effects can and do affect the condition, operation and effectiveness of the materiel, and the deleterious aspects of these environmental factors must be understood and taken into consideration during the "development" (design) phases, which precede the initial "procurement" stage in the life-cycle sequence. Consideration of environmental factors in testing of materiel, just as in its initial design, or in evaluation of modifications to improve its design must be antecedent to the beginning of this life-cycle. That is, the stage of the life cycle concerned with procurement involves not only production but must include or be preceded by all of the engineering processes necessary to it—design, development, testing, and approval for production.

A more or less effective "deficiency reporting" system makes known to the procuring agency (Developing Command) deficiencies, environmentally induced as well as operationally induced, which occur after issue of the materiel, as depicted by the broken lines in Figure 1-1. Depending upon the seriousness and urgency for correction of these deficiencies, they may be corrected in current production of the item and possibly even retrofitted to equipment already deployed or held for consideration of change in future production. Such modifications should be subjected to environmental testing, just as was the original design, in order that correction of the deficiency can be assured.

The several phases of the life-cycle sequence form the framework for the testing of materiel, particularly insofar as adverse environmental factors are concerned. Analyses of suitability must include aspects of storage, transportation, maintenance, and safety in addition to operational adequacy.

D. U.S. ARMY ENVIRONMENTAL TESTING

1. Testing Under AR 70-38

AR 70-38 is the governing document for adverse-environment testing of materiel for use by the Army. It specifically provides that "materiel under development is ***always*** tested in climatic chambers and usually undergoes additional, natural (or field) environmental tests."[5, para 1-9 (emphasis added)] Such testing is a significant part of the overall testing and performance evaluation process to which all Army materiel is subjected during its development, as delineated in AR 1000-1.

The testing process outlined in these regulations is essentially oriented to organizational responsibility rather than functional necessity. Practically, it is of utmost importance that preliminary research and investigative studies of new materiel consider the effects of the expected operational environment in its design. Such studies frequently necessitate exposure of component elements of the experimental or development prototype item or system to expected adverse conditions by, or under the direction of, the development engineer. These are frequently not acceptability tests of the component or item but experiments to develop funda

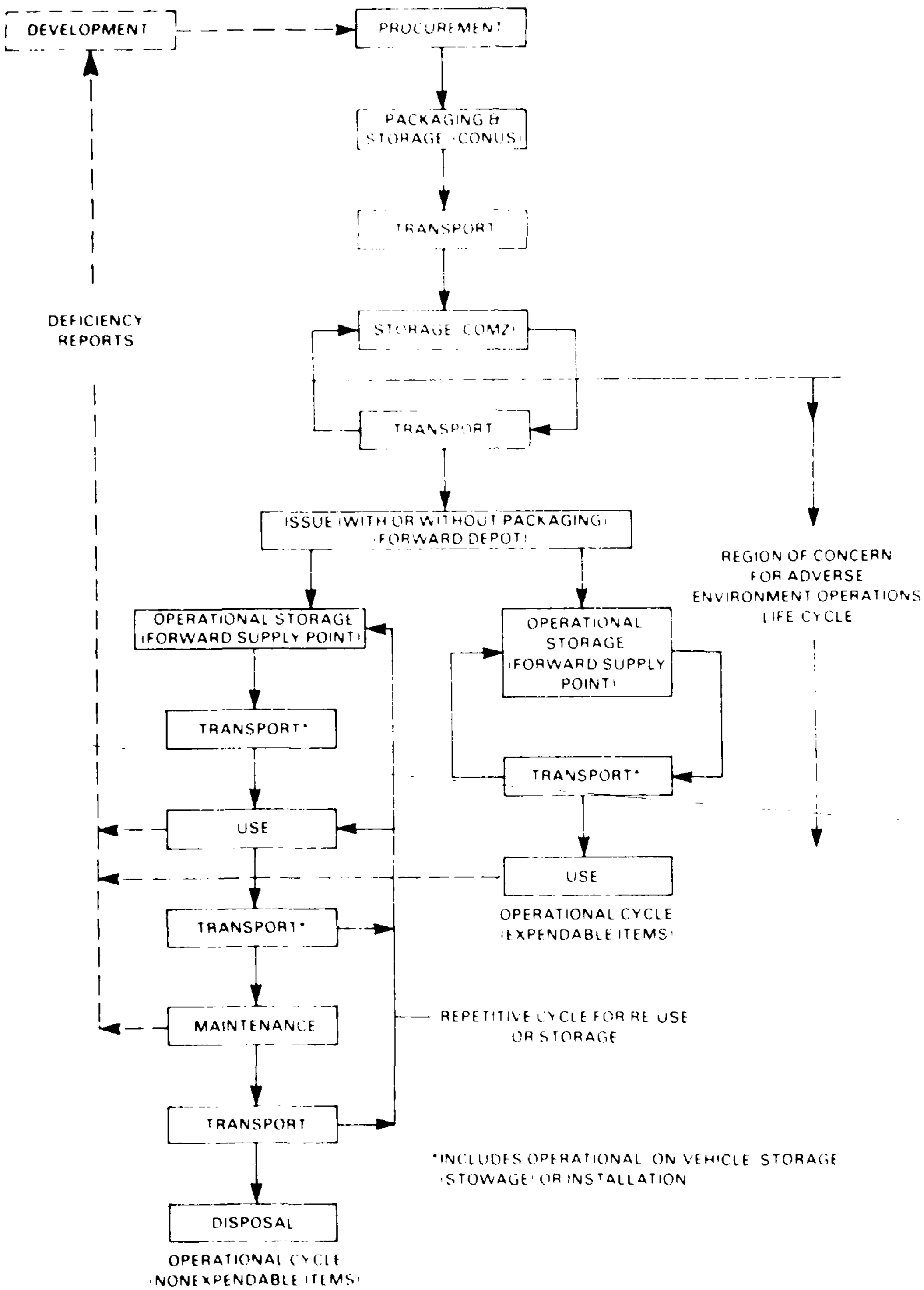


FIGURE I-1. LIFE CYCLE OF MILITARY MATERIEL (DEVELOPMENT/PROCUREMENT TO ULTIMATE DISPOSITION)

mental performance data to enable the design to progress or to test out a conceptual idea. Such tests are seldom routine (i.e., conducted under some standardized procedure) but are ad hoc or special purpose to obtain specific information for the development engineer. They should, perhaps, be better designated as "experiments" rather than tests. It is essential in such programs that the engineer requesting the information be the ultimate authority for the plan and conduct of the test. He should, of course, consult with other experts in the field in regard to such specialized areas of interest as adverse environmental impact in developing the test design.

Environmental chambers are, in general, used more for this type of experimental testing than is the natural environment; however, it is frequently desirable to conduct experimental programs under adverse natural conditions. This is particularly true for the desert environment, where many environmental factors that have impact on the performance of an item enter the picture—temperature, terrain, dust, soil characteristics and insolation being characteristic.

Another type of testing outside the formally prescribed research and development process that might also involve desert testing is that designated as [illegible] Testing [illegible]. This is normally conducted by the combat operational [illegible] for the purpose of determining the feasibility of a concept, system, or commercially available product to meet a possible military need. Such testing would normally produce operational (tactical employment) data rather than physical performance data.

2. **Natural Environment** vs Simulated Environment Testing

Environmental testing is the effective operation and evaluation of the performance of an item under adverse environmental influences—extremes of temperature, atmospheric pollution, terrain conditions, precipitation, humidity, solar and electromagnetic radiation, acceleration, vibration, and other such factors representative of the limits of normally expected service. The environment can be either natural or induced, and environmental testing can be either natural or simulated depending on the characteristics of the item being tested and the objectives of the testing.

Natural environment testing entails operation of the item and its consideration in the region or regions of the world, or analogous areas, where the extremes of adverse environmental conditions of interest can be found. The complete range of such adverse conditions to which an item designated for worldwide service could be subjected might, therefore, call for natural environmental testing in arctic, desert, tropic, mountain, and seacoast areas in order to be reasonably sure of its success in its service role. Such testing can be both expensive and time-consuming.

Simulated environment testing requires selection of extreme levels of adverse environmental factors against which the item is to be tested in an engineered (i.e., controlled) atmosphere—chamber, test cell, test fixture—so that the impact of the separate environmental elements can be measured and delineated.

It is evident that there are advantages and disadvantages to each type of environmental testing.

a. *Natural Environment Testing*

- Advantages

  - Combines all environmental elements of the region of interest so that interrelated, combined and synergistic effects are developed with proper or natural relative impact on the subject of the test.

- Adds supposedly minor or unrecognized environmental elements which would otherwise not be taken into consideration.

- Disadvantages:

    - Does not impose the extreme limits of specified environmental elements either concurrently or, in many instances, even separately. Acceptability for ceratin elemental performance limits may have to be deduced by extrapolation from less stringent operation during the test.

    - Test conditions are subject to the variability of weather and climate. Hence, test delays may be frequent or lengthy (seasonal).

    - Testing conditions are real-time; hence, no reduction in test time of life-cycle operations can be readily made through accelerated tests (i.e., increased loads, higher temperatures, increased dust concentrations, increased rates of precipitation, etc.)

    - Requires multiple test sites with increased cost of transportation, instrumentation, facilities, test support, and test personnel.

    - Requires increased numbers of test items and/or time for testing because of multiple test sites.

b. *Simulated Environment Testing*

- Advantages:

    - Enables adverse effects of specific environmental factors to be controlled and studied without relation to other elements. This may be of significant importance in early materiel development.

    - Major environmental elements may be tested in various combinations for detailed controlled study.

    - Performance under the specified extreme limits of each environmental factor may be examined.

    - Tests are not delayed by unacceptable weather conditions, travel to alternate test sites, or lack of test items (for successive or concurrent testing) and do not require multiple test facilities or test personnel. Certain highly specialized or unique chamber facilities would obviate this advantage if required to be utilized.

- Disadvantages:

    - Requires highly experienced, judgmental decisions as to the impact of specific environmental factors on the performance of the item under test, particularly as to what and how such elements will combine to produce synergistically adverse effects. Even with experienced test engineers, seemingly minor environmental factors, which ultimately caused serious deficiencies in service, have been overlooked or ignored.

- Except on very simple items, it may be very difficult or impossible to test all of the significant environmental factors and evaluate their individual as well as combined influences. This is especially true for new types of items where the experience to date has not been developed.

- Acquisition of facilities for testing under simulated environmental conditions may be inordinately expensive and require long periods for planning and construction, e.g., [illegible] Cold Temperature Facility, Detroit Arsenal High-Temperature Vehicle [illegible] Test Cell and Cold-Temperature Vehicle Cell, et al. Such facilities are of the nature of precisely controllable, engineering instruments of [illegible] size. For many major military items, there are few or no commercial facilities [illegible] adaptable for such testing, hence no possibility of contracting out [illegible] such testing.

- Removes influence of operator in that such testing is generally conducted in a laboratory environment where an operator, as such, may not even be present. Hence, operator effects, such as variation in training and experience, physical condition and characteristics, skill, judgment and technique (habits), are missing.

- Except in special chambers, large complete systems often cannot be operated fully and performance degradation is therefore not measured at the extreme conditions.

- Material deterioration results do not predict real-world results with any degree of confidence."

c. *Practical Aspects of Environmental Testing*

Dr. E. M. Haverland has stated: "The greater the discrepancy between the environmental conditions and equipment used for activities during testing and those encountered by the equipment during its service life, the greater the risk that the testing will fail to discover inadequacies in the equipment, if inadequacies exist . . . It is true that chamber or laboratory testing can be controlled, so that it is standardized and repeatable. But these advantages are often purchased at a cost of reduced validity in the field." He concluded: "TECOM's (U.S. Army Test and Evaluation Command) present policy on natural environmental testing is based on its extensive corporate memory . . . as well as the regulatory guidance of AR 70-10, 70-38 and 1000-1. TECOM insists that all new systems be tested in climatic chambers. TECOM recommends that all new systems intended for high density employment also be proved in adverse natural environments. When the latter tests are infeasible because of dollar, time (or other program) constraints, TECOM attempts to assess the risk involved in its independent evaluation report."

The adverse synergism of combinations of environmental factors obtained in natural or field testing cannot be overemphasized. Over the past years and with many different types of equipment, there have been many examples of failures of chamber testing to disclose deficiencies that were later found in natural environmental tests or operational service after the item was deployed. Ideally, new designs for equipment should be reviewed by environmental experts to ensure that their experience and knowledge are utilized to counter the potential hazards of the environment. Practically, this is seldom accomplished, and unless the designer or development engineer is well experienced in this area, deficiencies will result. The principal adverse conditions — high temperature, dust infiltration, grade performance, etc. — may be adequately accommodated because they are well defined (specified) and recognized by the designer, but combinations of these and other unrecognized or assumedly minor factors may be found to have highly detrimental effects in the field. Some examples that have been observed are:

1. *Dust ingestion by helicopter turbines.* This well publicized deficiency occurred in Viet Nam from unanticipated operation of helicopters in hovering mode during loading operations in critical situations. Dust and debris stirred up by rotor downwash had not been considered as a factor in designing the aircraft and were ingested by the turbines, causing premature failure.

2. *Cracked tail rotor pitch control components.* Cold testing at Ft. Greely of the OH-6A helicopter disclosed cabin heating problems caused by drafts and insufficient capacity of the heating system. It also developed cracked nylasint liners in the tail rotor unit after cold start and flight operations in below 0°F (-18°C) ambient conditions. The liner cracking was not observed in chamber testing, apparently because the helicopter could not be adequately exercised.

3. *Unpacking of projectile.* In testing of a guided projectile at Ft. Greely, unpacking and handling of the projectile was unacceptably slow because of the cold-weather clothing worn by the handlers. This and a cold weather design fault found in the projectile itself might have been found in previously conducted chamber testing but was not.

4. *Intake air duct clogging.* Ingestion and clogging of vehicle intake air ducts by vegetation (dry grasses, tumbleweeds, greasewood, etc.) has occurred even though normal filters were installed. Chamber testing did determine the effects of normally expected dust in the intake air, but the effects of the debris thrown up by vehicle wheels and tracks were unanticipated until revealed by field testing.

5. *Drivetrain blockage.* Although not, perhaps, as prevalent in desert environments as in those embodying more dense vegetation, blocking of driving components — wheels, propeller shafts, steering mechanisms — by tough vines and broken branches or masses of packed weeds and grasses does occur in field operations and cannot be effectively simulated in a chamber. The designer can, perhaps, visualize such conditions and try to overcome them in his design, but only field testing can prove such designs.

Although sometimes first found as a result of field testing, deficiencies attributed to cracking, binding, or distortion of components and caused by differential expansion of component parts in extreme cold or heat; condensation from intrusion of humid atmosphere; dust and snow infiltration; microbial growth, insect damage and similar singular effects should be evident from properly conducted chamber tests. That they are not discovered until field tests or service use of the equipment is generally attributable to inadequate chamber testing. It is the effect of these climatic factors in combination, which is difficult or impossible to simulate, that is more readily determinable by field testing than by chamber testing.

II. DESERT ENVIRONMENTS

A. THE DESERT

1. Climate

Although the desert environment is generally depicted in terms of Climatic Design Daily Cycle A1[5] with a hot-dry cycle, it should be recognized that deserts may exist with climatic cycles of A2, C1 and C2 as well; thus, many other characteristics must be considered in the definition of a specific desert than just high temperatures and aridity. The principle criterion, however, is climatic; i.e., aridity, whereby the potential evaporation rate from the ground surface exceeds precipitation. Deserts exist in temperate or cold regions as well as hot, even though high temperature is usually assumed to be a principal characteristic of the desert.

Characteristics of topography (terrain geometry); soil; vegetation; and even fauna are also essential in defining the limitations and natural constraints imposed by the desert. The characteristic desert aridity results in sparse vegetation on thin soils of low organic content, readily eroded by rain or wind. Additionally, intense sunlight, wide-ranging seasonal and diurnal temperatures, and sudden, violent wind and rainstorms are typical. The whole of these elements must be considered to characterize particular desert environments.

Brooks, after consideration of numerous sources, has proposed the following definition,[14, paraphrased] which is concluded to be quite apt:

> "A desert is a region with an arid climate in which the potential evaporation rate exceeds the precipitation (annual precipitation rate). Over a long period of time, the arid climate results in the characteristic scanty vegetation (xerophytic or drought resistant) of such regions. Lack of vegetation, in turn, results in soil of low organic content and contributes to the characteristic shaping of topography by water and aeolian forces."

By this definition it may be seen that even though precipitation occurs, possibly even at high rates in terms of quantities per unit of time (inches per hour), the annual or seasonal evaporation rate is such that evaporation exceeds the total precipitation for the period, and an arid soil results. Brooks further states (ibid):

> "This definition infers the unsuitability of a desert for agriculture due to lack of water and poor soil condition. It also infers the limited population which a desert can support without artificial supplies of food and water. The limited population, in turn, infers the lack of developed communication systems. The type of topography is also inferred, being due to rock disintegration rather than decay. Temperatures are inferred by the requirement for a relatively high evaporation rate. (Extremely high temperatures are not typical for all deserts, since low precipitation requires only a relatively low evaporation rate (to maintain necessary aridity) and correspondingly, relatively low temperatures can occur and still achieve adequate evaporation rates, e.g., the Gobi and Great Salt Lake Deserts.)"

Of the 56 million square miles of land area of earth, about 19 percent or 10.5 million square miles is considered "arid", with another 8 million square miles categorized as "semi-arid". The great deserts of Africa and the Middle East lie astride the Tropic of Cancer; those of South America and Australia are on the Tropic of Capricorn. Only those of middle Asia and the western United States lie at higher latitudes, Figure

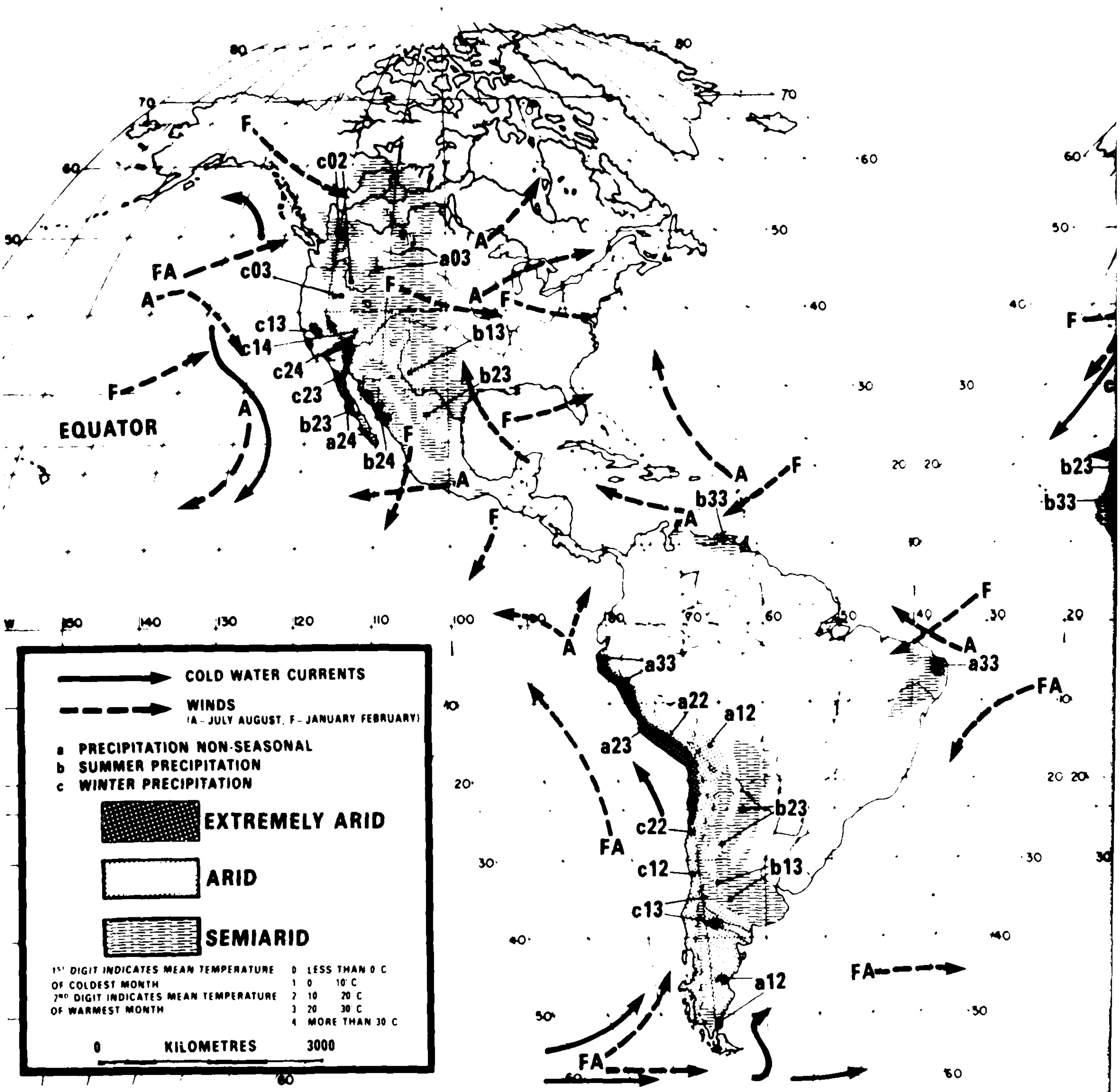
II-1. Climatically, the equatorial areas between the tropics are Climatic Cycle B3, hot-humid, nonseasonal, or seasonal as they approach the tropic latitudes.

2. Deserts in General

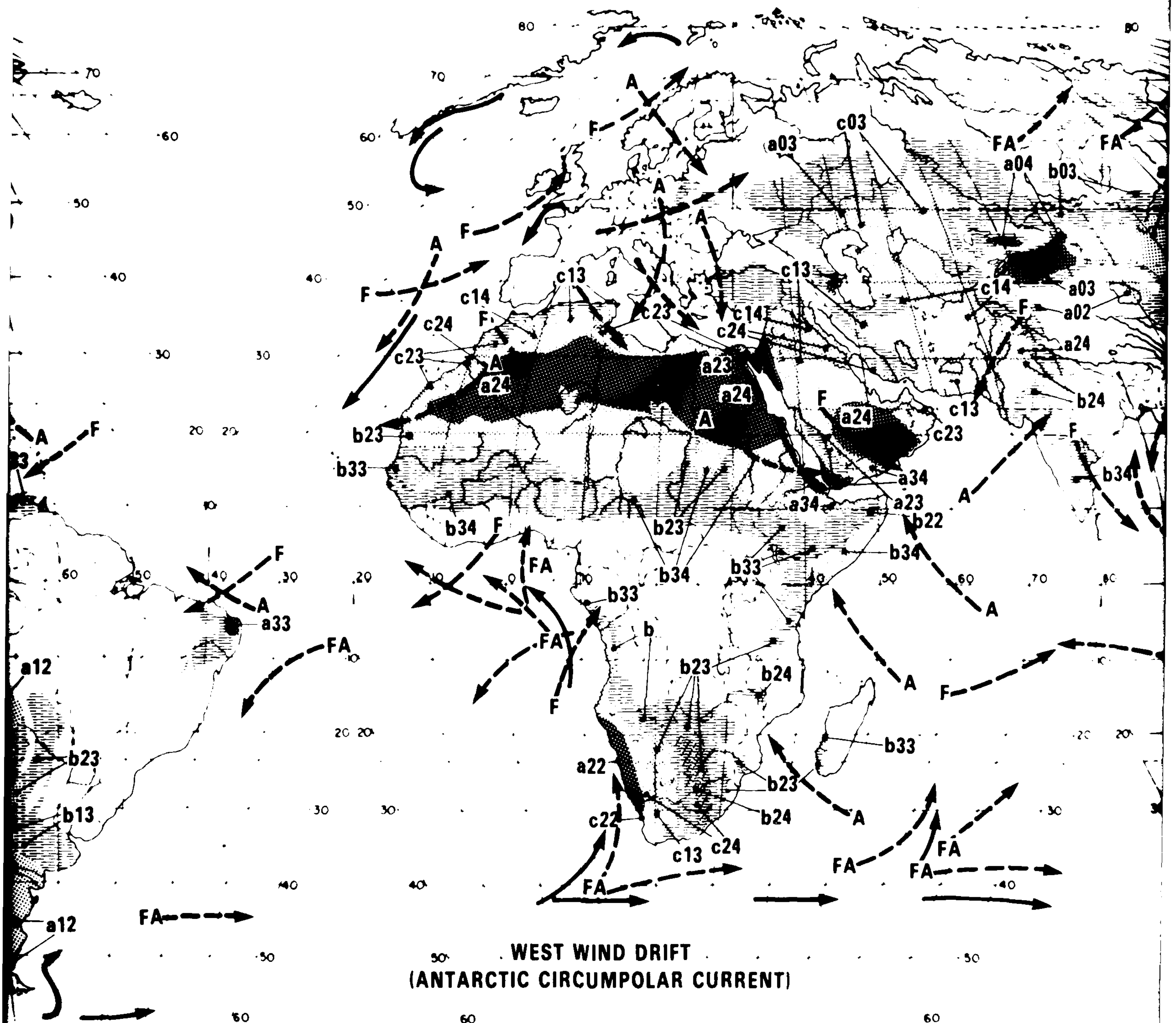
The desert areas are Cycle A1, hot dry; Cycle A2, basic hot dry; Cycle C1, basic cold; and Cycle C2, cold. The 16 major desert complexes found in seven areas of the world may be subdivided into small, contiguous regions having more consistent distinctive characteristics, but even within these smaller elements, wide variability exists, particularly with regard to topography (terrain geometry); soil (geologic factors); and vegetation. Table II-1 delineates these desert areas, the climatic categories of which are generally consistent within a given region unless there is extension into higher latitudes or elevations, i.e., change from Cycle A1 to A2 or C1. Comparative characteristics of major deserts are indicated in Table II-2. Figure II-1[16] shows these world regions, which are classified as deserts by reason of climate, terrain, soil, and biota. An illustration of the great variety of terrain features and soil characteristics that are met in most desert regions is shown in Figure II-2[17] for the Sahara Desert. It is evident that the typical desert scene of rolling sand dunes is present in many areas of this desert, but there are also bare, crusty plains, gravel and rocky floors, salt basins, rocky outcrops, and mountains, all cut and crisscrossed by eroded stream beds, dikes, alluvial outwashes and escarpments. Soil is thin to nonexistent, as is also vegetation.

The mechanisms of the Earth's climate and terrain that result in the generation of the major deserts are worldwide in scope and complex in their interrelationships. A United Nations Conference on Desertification (1977) discussed these factors as:[18, paraphrased]

> Significant rainfall is always caused by uplift of humid air, but rain does not fall even from humid airstreams unless its stability is disturbed to cause uplift. Many arid and semi-arid regions, such as Pakistan and northwest India (Thar desert), have highly humid air for major portions of the year, but because it is stable (not uplifted), no rain occurs. Air is stable when its temperature decreases only slowly with altitude, but its temperature may even rise (inversion), as may occur when moving over cold ocean surfaces; e.g., Atacama desert of South America, Namib of Africa, and the southwestern deserts of Australia.
>
> The main causes of aridity are:
>
> (i) Widespread, atmospheric subsidence
> This is inherent in the mechanism of the general atmospheric circulation of the Earth, producing regions of vertical subsidence in the regions of the Tropics (28.6 N and S of the Equator) with relatively minor seasonal shifts northward during June to August and southward during December to February. The Sonoran Desert of Mexico and southwestern USA; the Saharan - Southeast Asian, the Namib-Kalahari of southern Africa; and the Australian deserts all lie beneath these regions of subsidence.
>
> (ii) Localized subsidence
> This is generally induced by major mountain barriers that cause uplift of humid air on their windward faces, followed by subsidence on the leeward side. Westerly winds produce such aridity in western North America, in southern Argentina, and parts of inner Asia.



COLD WATER CURRENTS
WINDS
(A - JULY AUGUST, F - JANUARY FEBRUARY)
a PRECIPITATION NON-SEASONAL
b SUMMER PRECIPITATION
c WINTER PRECIPITATION
EXTREMELY ARID
ARID
SEMIARID
1ST DIGIT INDICATES MEAN TEMPERATURE OF COLDEST MONTH
2ND DIGIT INDICATES MEAN TEMPERATURE OF WARMEST MONTH
0 LESS THAN 0 C
1 0 10 C
2 10 20 C
3 20 30 C
4 MORE THAN 30 C
0 KILOMETRES 3000
EQUATOR


WEST WIND DRIFT
(ANTARCTIC CIRCUMPOLAR CURRENT)
a03
c03
a04
b03
a03
a02
a24
b24
c13
c23
c14
c13
c23
c24
c14
c24
a23
a24
a24
a24
b23
b33
b34
b23
b34
a34
a34
a23
b22
b34
b33
b33
b
b23
b24
b33
a22
b23
b24
c22
c13
c24
a33
a12
b23
b13
a12
FA
F
A

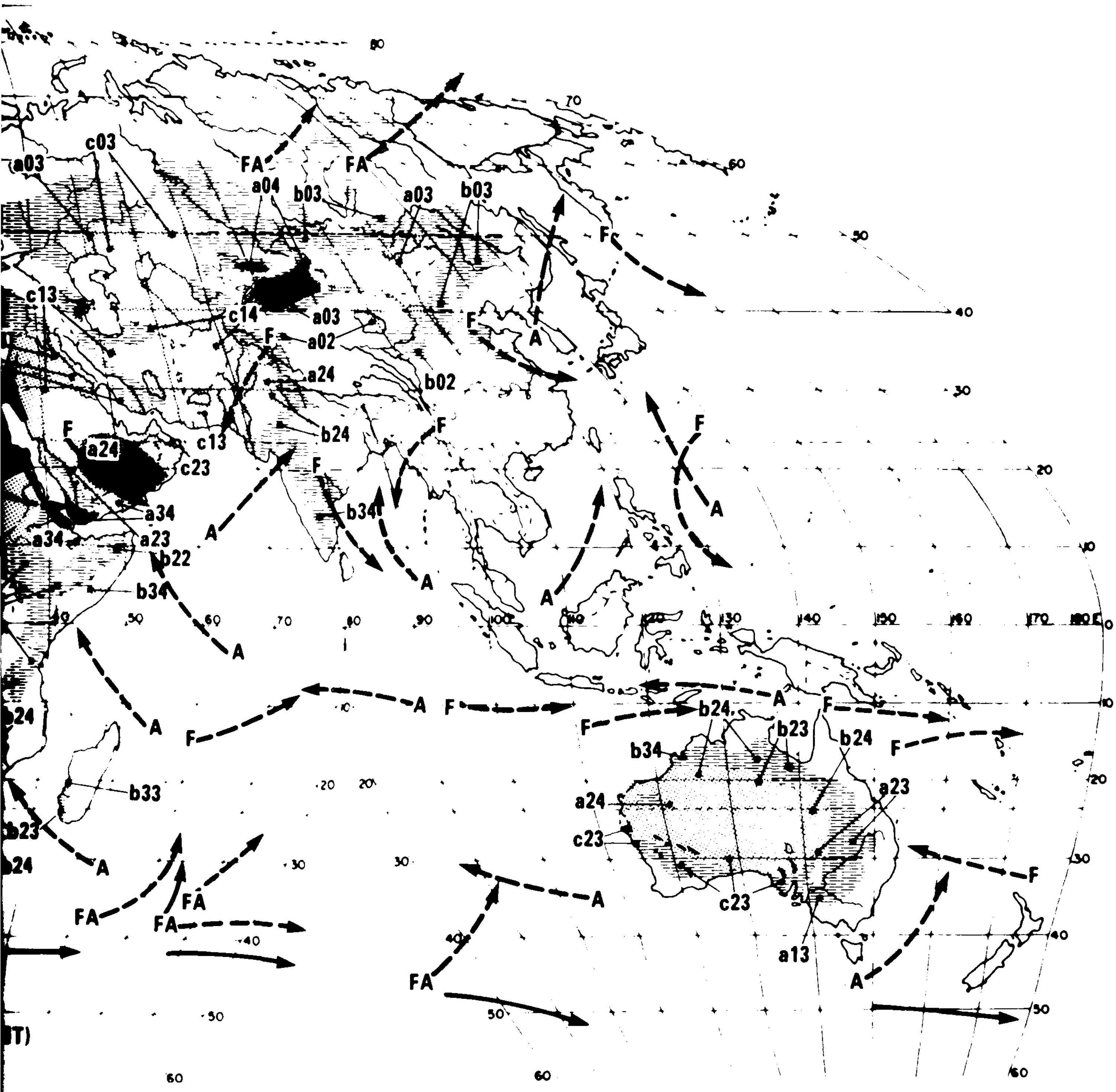


FIGURE II-1. WORLD DESERTS[5,16,18]

TABLE II-1. DESERTS OF THE WORLD

Africa	Code*
Kalahari	Ab23/Ac13
Namib	Ea22
Sahara	$(3.4 \times 10^6 m^2)$
Great Tanezrouft	Ea24
Spanish Sahara	Ac23/24
Southern Sahara	Ab23/Sb34
Libyan Erg	Ac13/Ea24
Grand Erg Occidental	Ea24
Grand Erg Oriental	Ea24
Somali Chalbi	Ab24
North America	
Chihuahuan	Ab13/23
Bolson de Mapin	Ab13/23
Great Basin	Ac02/03/14
Black Rock	Ac02
Painted Desert	Aa03
Great Sandy	Ac03
Sonoran	Ac24/Ab24/Ea24
Mojave	Ac23/24
Disierto de Altar	Ea24 Ab24
Baja Peninsula	Ea24/Aa24/Ab23
South America	
Atacama	Aa12/22
Peruvian	Ea23-33
Monte Patagonian	Ab23-Sb23/Ac13-Aa12-Sa12
Venezuela	Ab33
Brazil	Aa33

Asia	Code*
Gobi	
Ordos	Aa03
Ala Shan	Aa03
Bei Shan	Aa03
Tsidam	Aa02
Gachoun Gobi	Aa04
Takla Makan	Ea03
Turkestan	
Kara Kum	Ac04
Kyzyl Kum	Ac03
Middle East and South Asia	
Arabian Desert	
An Nafud	Ac14/Aa23-24
Rub' al K'hali	Ea24/Ea34
Yemen	Ea34
Negev	20
Iranian Desert	Ac04-Ac14
Dasht-e-Kavir	Ac13
Dasht-e-Lut	Ac13
Dasht-e-Margo	Ac14
Kavir-i-Namak	AC14
Dasht-e-Naomid	AC1
Indian Desert	
Thar	Aa24-Ab24
Australia	
Arunta (Simpson)	Ab23
Gibson	Aa24
Great Sandy	Ab24
Great Victoria	Ac23
Sturt	Aa23

*Meig's Climatic Code - A, p, t_l, t_h -- (aridity) (precipitation) (mean low temp.)(mean high temp.)[16]

Aridity
- E - extremely arid
- A - arid
- S - semi-arid

Precipitation
- a - nonseasonal precipitation
- b - major precipitation in summer
- c - major precipitation in winter

Temperature
- 0 <0°C
- 1 0°-10°C
- 2 10°-20°C
- 3 20°-30°C
- 4 30°C

TABLE II-2. COMPARATIVE CHARACT

	SONORAN	CHIHUAHUAN	ATACAMA/ PERUVIAN	MONTE- PATAGONIAN	KALAHARI- NAMIBIAN		SAHARAN	SOMALI CHALBIAN
TEMPERATURE(°F)					K	N		
High	134	120	92	118	111	107	136 4	122
Low	30	-6	42	-22	16	25	31	37
Mn Daily Max-Sum.	107	104	80	90	94	75	110	11
Mn Daily Min-Win.	9-42	27-40	54	31	34	45	37	35 44
PRECIPITATION								
Annual (in.)	2.2	12	0	5	12	1	0 0 3	6
INSOLATION	[Max theoretical = 1322 w/m²/hr: Actual depends on latitude (Angle of incidence, cloud cover, etc.]							
Mn Daily Max.(w/m²/hr)								
WIND VEL. (mph) (Note 1)	5-8	5-8	1-4	2	2-4		4 7	4 5
HUMIDITY								
Mn. Summer(% RH or DP)	45-60	68-72	62-66	45-66	71	91-95	50 63	57 65
OZONE								
DUST (Particle size < 150 μm) Bp 120-126)								
Natural (g/m³)	(Dust concentrations depend primarily on wind velocity and height above ground surface. little variation with respect to regions.)							
On Roads								
TERRAIN (% of Area) (A)								
Mountains	8						16	
Badlands/hills/fms	34						19	
Flats/gravel	24						39	
Playas/salt flats	3						7	
Dunes	0.6						18	
Salt lakes, marshes								
Total Area (x 10⁶mi²)	0.5	0.18	0 14	0 26	0 22		3 5	0 3
CLIMATE (Note 2)	A2,A1	A2,A1	A2,A1	A2,A1	A2,A1		A2 A1	A1,A2
Fauna (Note 3)								
Man affecting	ARI	ARI	ARI	ARI	ARI		ARI	ARI
Mtl. affecting	B1	B1	B1	B1	B1		B1	B1

Note 1 Excludes tornadic winds

Note 2 AR 70 38 Climatic Daily Cycle Categories (A1) Hot dry (A2) Basic Hot (C1) Basic Cold C2 Cold (major minor areas)

Note 3 Presence of damaging poisonous or health affecting (A) spiders scorpions (R) snakes lizards (I) insects ticks (M) animals (I & M particularly as disease vectors B Bacteria Fungi

Note 4 Insignificant within YPG but nearby area of 80 + mi² available

MPARATIVE CHARACTERISTICS OF MAJOR DESERTS

HARAN	SOMALI CHALBIAN	ARABIAN	IRANIAN	THAR	TURKESTAN	GOBI TAKLA MAKAN	AUSTRALIAN	YPG	AR 70 38 LIMITS
—									
136.4	122	123	127	126	122	115	123	123	120
31	37	19	4	30	19	45	20	22	50
110	11	105	108	106	102	71 90*	95 101	106	90 120
37	35 44	38	24 27	46 51	23	2[illegible]	30 2	42 4	
0-0 3	6	4	3 1 6 0	6 5 9 0	3 2 8 1	0 8 [illegible]	5 0 12 0	3 4	
4-7	4 5	4 10	2 3	6 8	3 7	3 9	NA	6 1	73 steady 95 gust (fps)
50-63	57 65	50 60	46 52	70 73	55 66	45 55	25 40	64	220 μg m[illegible]
(with respect to regions)									0 177g m[illegible] 1 06g m[illegible]
16			18		28			25%	
19			26		2[illegible]			16%	
39			31		2[illegible]			57%	
7			6		14				
18			19		1[illegible]			(Note 4)	
3.5	0 3	1 0	0 15	0.23	0 75	[illegible]	1 3		
A2,A1	A1,A2	A1,A2	A1,A2	A1,A2	A2,C1	A2 C[illegible]	A2 A1	A2	
ARI B1	ARI B1	ARI B1	ARI B1	RI B1	ARI B1	R B[illegible]	ARI B1	ARI B1	

(B) Bacterial Fungi

Glossary

Agaba, Agaba	Pass, ascent	Gara	Bank, cliff
[illegible]	[illegible]	Jebel	[illegible]
Argub	Ridge, row	[illegible]	Water course
[illegible]	Pass	[illegible]	Well
[illegible]	[illegible] river	[illegible]	[illegible] watering place
[illegible]	Crescent dune	[illegible]	Cliff, bluff
[illegible]	Sandy area	[illegible]	Water shed
[illegible]	Fine sand	[illegible]	Pass, ascent
[illegible]	Road track	[illegible]	Pass
[illegible]	Sandy plain	Feggara	Cliff, ascent
[illegible]	Depression	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Erg, Ergs	Dunes, dune field	[illegible]	Dune
Fesh Fesh	Powdery chalk	[illegible]	Sand
[illegible]	Hill, mountain	[illegible]	Water course
Ghard	Dunes	Sabakha, Sebkha	Salt marsh, bog
[illegible]	Rocky hill	[illegible]	[illegible] plain
[illegible]	Dead valley	Seil	Flood bed
[illegible]	Cliff, escarpment	[illegible]	Branch wadi
[illegible]	Escarpment	Serir	Gravel desert
[illegible]	Gorge, valley	[illegible]	Saddle
Hamada	Stony plain	[illegible]	Waterhole
Hass	Waterhole	Wadi, Oued	Water course
[illegible]	Cave	[illegible]	Stone, rocky edge

Abbreviations

A	Ain	waterhole
B	Bir	well
D	Dahr	mesa tableland
G	Gara	[illegible]
HA	Hamada	rock flat
J	Jebel	mountain
K	Khor	dry river
Q	Qasr	fort
S	Sebcha	salt flat
W	Wadi	water course

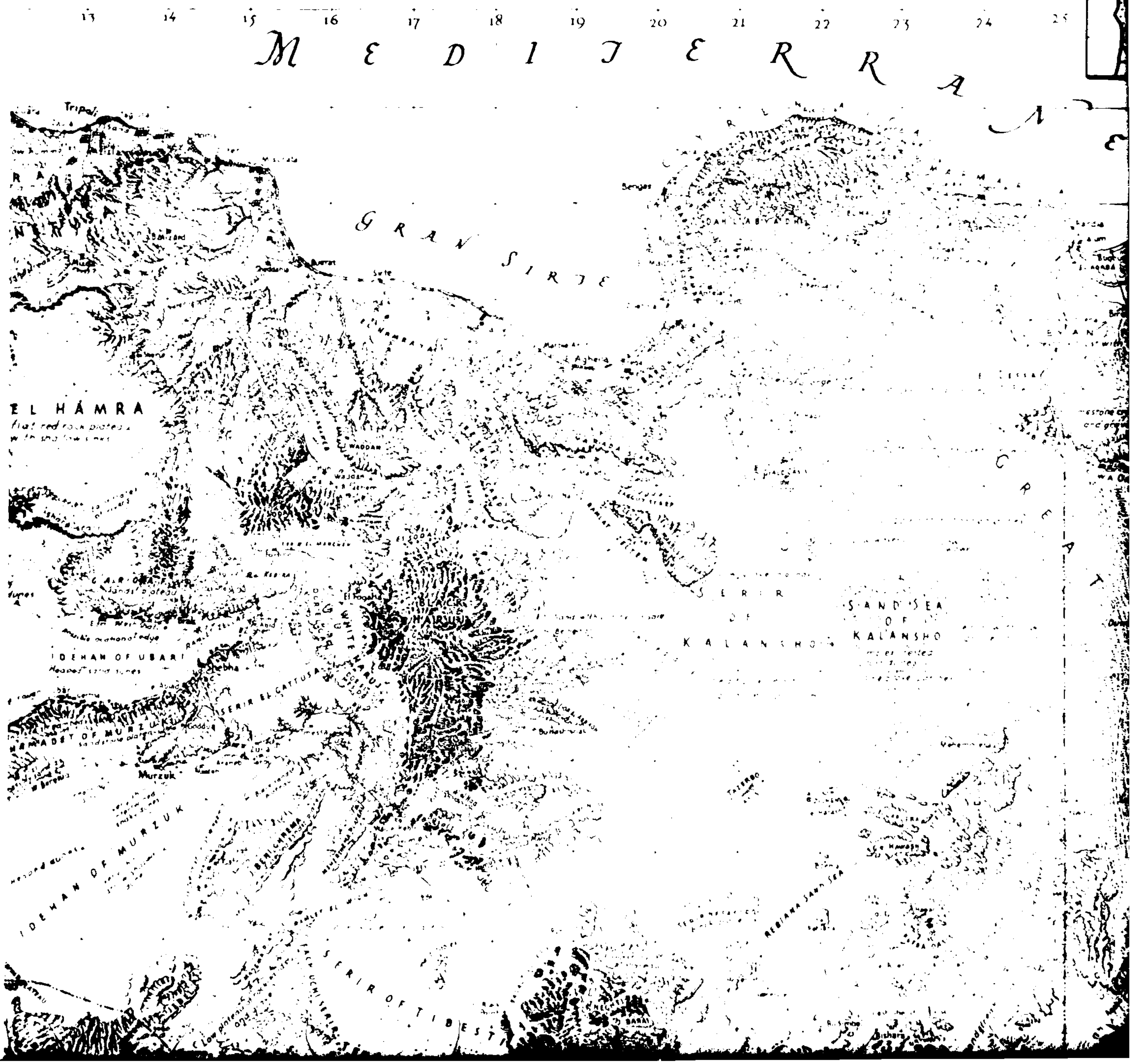
IN FRENCH

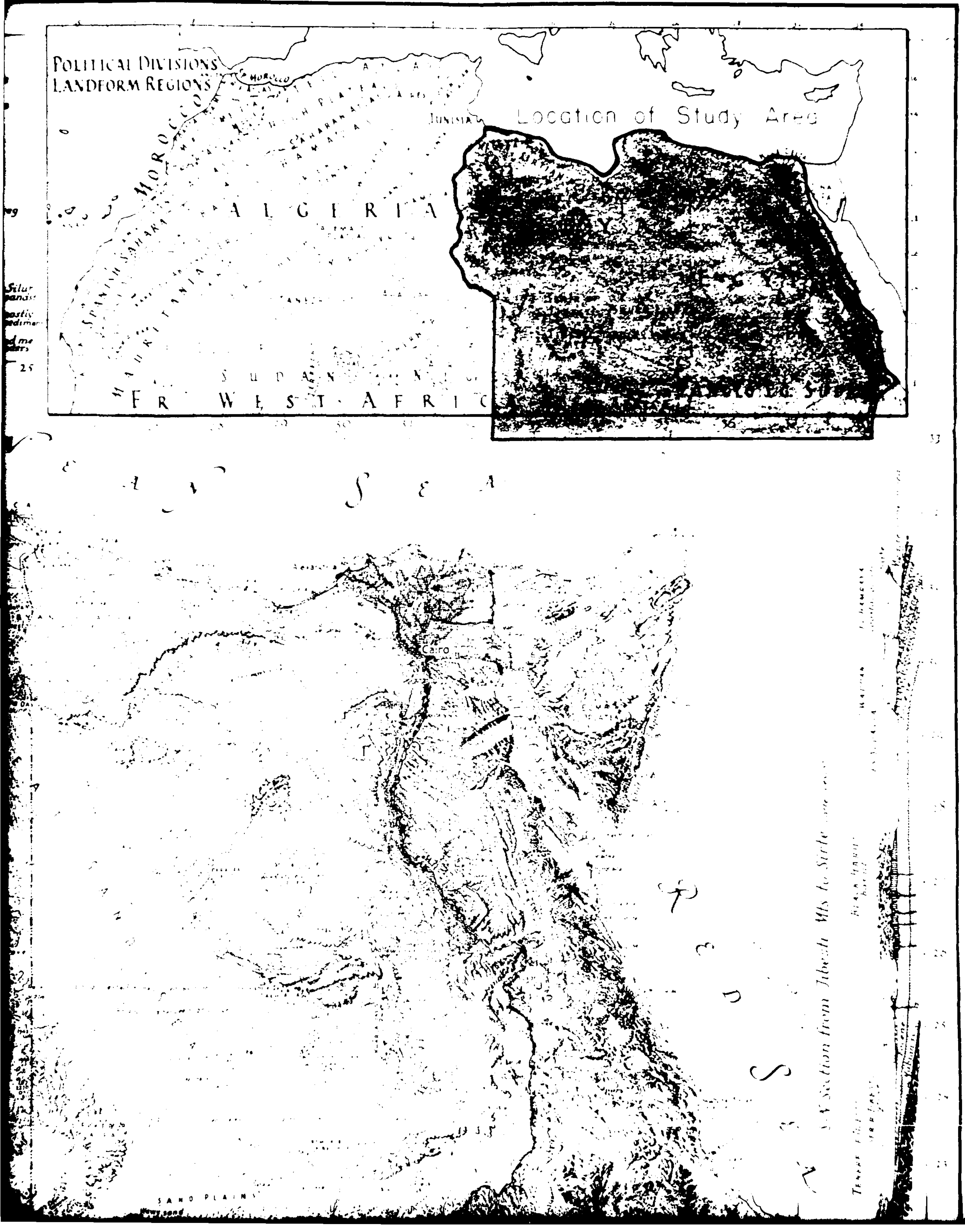
D^{a}	Daia	basin, sink
Dj	Djebel	mountain
G	Gour	valley
H	Hassi	well
Og	Oglat	many wells
O	Oued	water course

The designations Ain Bir, Hassi Oglat for water holes is sometimes omitted

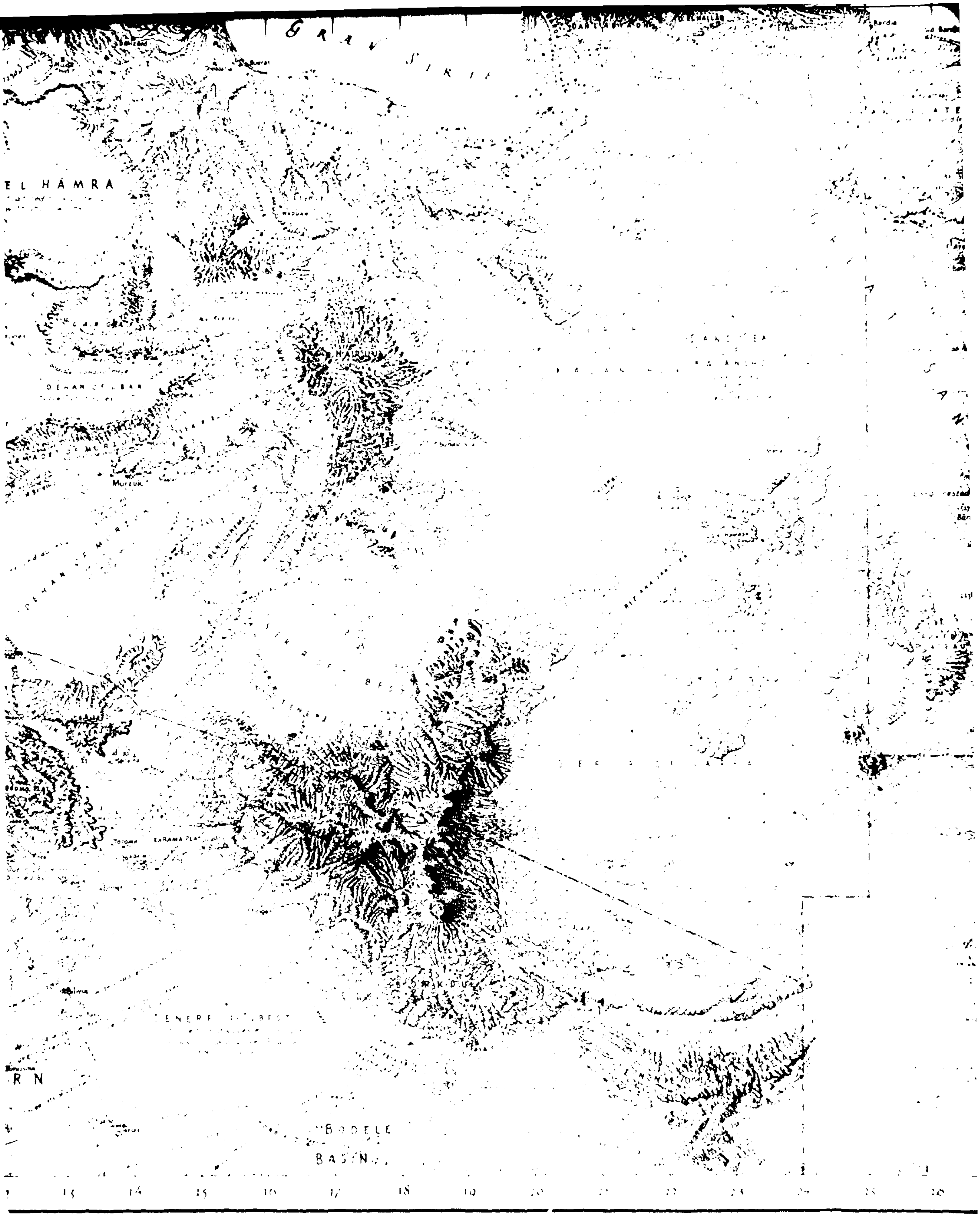
Symbols

- Motor road
- Trail
- Railway
- Canal
- Settlement
- Water hole
- Oasis not shown in the Atlas lands
- Jebel, mountain
- Dendritic sand streams
- Dissected plateau
- Wind etched lime stone
- Knobby sandstone
- Lava
- Crystalline lowld
- Salt and sand flats
- Salt and [illegible]
- Buried [illegible]
- Heaped dunes
- [illegible]
- [illegible]
- Rock holes
- Salt lakes or flats
- Knot rows mostly [illegible]
- Closely set [illegible] mostly [illegible]
- Hamada with incised [illegible]

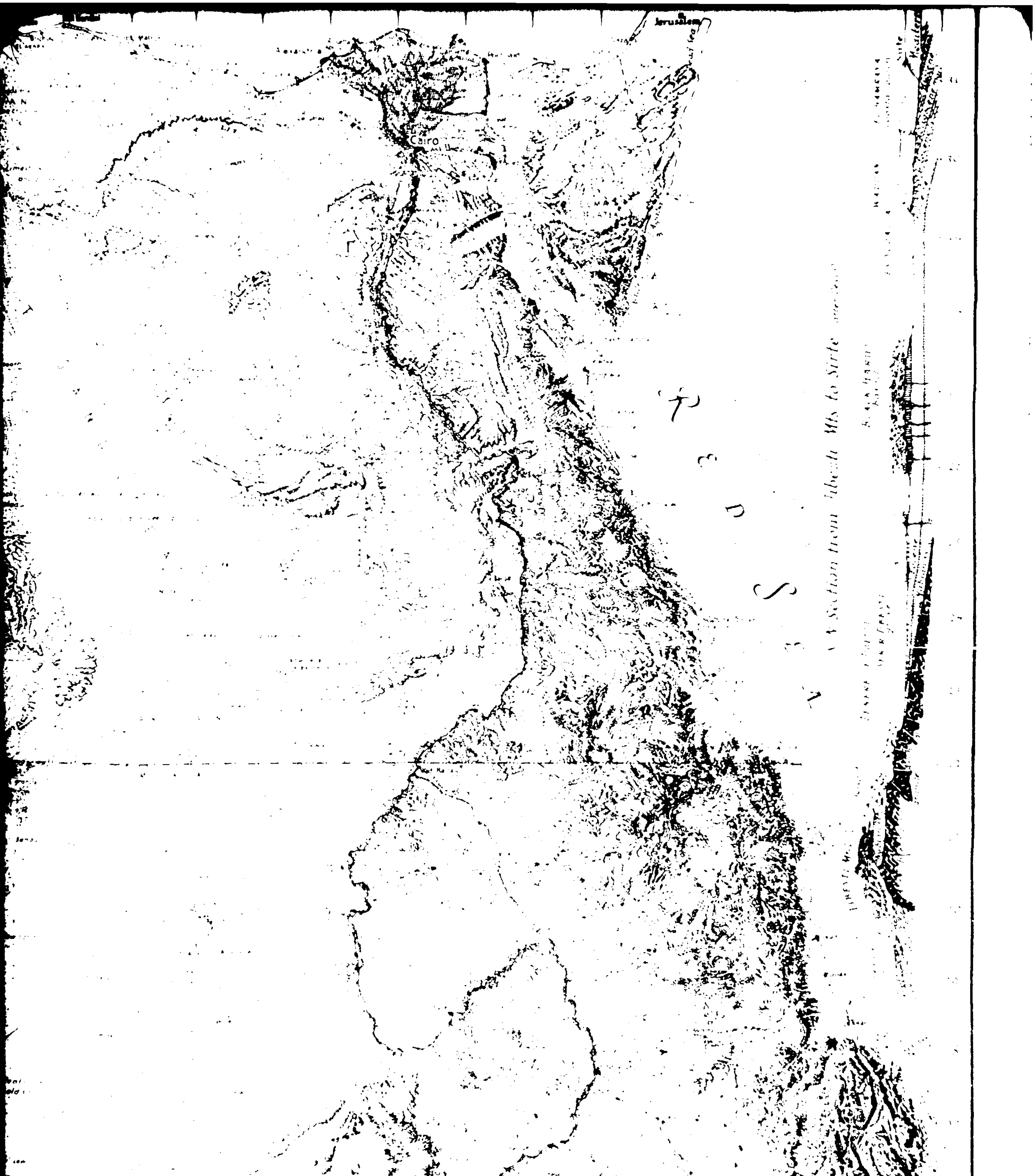




POLITICAL DIVISIONS
LANDFORM REGIONS
Location of Study Area
MOROCCO
ALGERIA
SPANISH SAHARA
SUDAN
FR WEST AFRIC
Cairo
SAND PLAINS



LANDFORM MAP OF NORTH AFR



NORTH A A B

(iii) Absence of rain-inducing disturbances

Steppe areas, such as Texas and Oklahoma, may be rainless for long periods, even when covered by humid air off the Gulf of Mexico if no systems causing uplift of that humid air pass through the region. The aridity of Mediterranean summer occurs similarly, and in both cases, subsidence from the general vertical circulation contributes further to such aridity.

(iv) Absence of humid airstreams

Some regions of the world are just too remote from regions where humid airstreams exist for any precipitation to occur with any regularity. The innercontinental regions comprising the deserts and steppes of central Asia are cut off from the humid monsoonal winds from the south by the Himalayas and the Tibetan plateau, and only dry, cold air reaches them when winds are from the north. Western Africa is subject to the almost unbroken dominance of dry, mid-Saharan airstream. In such regions, only highly erratic atmospheric conditions will produce rainfall.

In summary, these factors result in the production of the world's deserts, as follows.

3. Air and Ocean Current Circulation

In North and South America, southern Africa and Australia, the prevailing winds, both winter and summer, are from the Arctics toward the Equator and from the west, i.e., onshore. The major Saharan winds are toward the south and west in the winter (offshore toward the Atlantic Ocean) and southerly from the Mediterranean in summer, except in the southwest regions where the wind is to the north. The Arabian penninsula, Iran, and the Thar are subject to north and northwesterly winds in the winter but west or southwesterly to south winds in the summer. Cold ocean currents—the Humboldt along western South America, the California along western North America, the Benguela by southern Africa, and the West Australia current—coupled with mountain ranges in the North and South American continents, cause massive air drying, Figure II-1. Air flowing through the other desert areas is predominantly from the Asian or eastern European interior, originating initially from the cold, dry Arctic regions. Any moisture it might acquire in passing over intermediate forested or plains regions is wrung out by intervening mountain ranges.

4. Topography and Terrain

Aridity and temperature effects are not, perhaps, the most critical adverse aspects affecting military operations in desert environments. Of major importance are the terrain and soil conditions characteristically encountered in these regions. Numerous studies of these factors[14, 19, 21, 22] have led to descriptive classifications that allow them to be categorized in terms in which difficulty of traverse or degradation of operation in other ways is implied.

Deserts can be broadly categorized as sandy, stony, or rocky (ibid), but in relation to defining the physical characteristics upon which limits of operation of military materiel can be established, much more detail must be considered relating to mobility (trafficability, surface roughness and penetration, slope, profile); dust and obscuration; cover; or concealment. These have been expanded under the following broad types to include clay deserts and subclasses in each category to provide more descriptive delineation:

a. *Sandy Deserts*

1. Sand sheets
2. Clay pans and gravel deposits

3. Sand dunes
4. Heterogeneous deposits

b. *Gravelly Deserts (predominant type)*

1. Desert pavement (gravel-covered plains, serir)
2. Thin gravel veneers (hammadas)
3. Alluvial outwashes and valleys
4. Gravel terraces
5. Gravel slopes

c. *Stony and Rocky Deserts*

1. Rocky surfaces
2. Rock-and boulder-strewn surface
3. Pang yang depressions
4. Lava flows
5. Steep-sided hills, mesas
6. Rounded hills, low mountains
7. Badlands (malpais)
8. Rubble-covered surfaces
9. Dissected plateaus, cliffs, escarpments

d. *Clay Deserts (limited occurrence)*

1. Clay plains
2. Clay pans (playas, evaporative residues)
3. Clay slopes (shale-derived)
4. Eroded clay landscapes (clay terraces, yardangs)
5. Saline and alkaline pans or areas (evaporative residue)
6. Miscellaneous (kavirs/salt beds, beaches, etc.)

e. *Mountains*

1. Ranges
2. Block mountains
3. Volcanoes
4. Domes, inselbergs, buttes

The geology of the desert areas of the world is essentially unchanged over the past 10-50,000 years, with few possible exceptions (Rift Valley, Africa). The mountains, hills and plains and the drainage basins found today in desert areas are the underlying structures of these areas as they have existed for millenia

Climate, on the other hand, has unquestionably changed in many of these regions.* The production of alluvial outwashes or fans, eroded landscapes, clay or alkaline pans, gravel and rocky floors, and other typical desert terrain is the outcome of both earlier wetter climate and later, characteristically intense, desert rains after denudation occurred. After precipitation dropped sufficiently to cause aridity and a change to sparse desert vegetation, aeolian forces caused further denudation and scouring of soil from the gravel and rocky sub surface and the production of sand dunes and typical desert "floors." Figures II-3, II-4, II-5 show the desert terrain structures resulting when water is not absorbed into the soil but washes freely over the surface and wind is not obstructed by vegetation.

In these arid areas cloud cover is virtually nonexistent for long periods, thus solar radiation (insolation) reaching the ground is high, but radiation to the sky at night is also high. Not only can daytime maximum air and ground surface temperatures be high but also wide variations between day and night temperatures can occur. The resulting expansion and contraction of surface layers of many stony materiels develops spalling and cracking and the production of small flakes and even dust, easily moved by hydraulic or aeolian forces.

Various soil types have different, potentially adverse effects in terms of dust generation and erosion of surface soils by motor vehicle traffic or aircraft downwash or naturally by the wind. There is a wide range of particulate sizes characteristic of various soil constituents, and some types of source materiels are much more abrasive than others.

Because sand and dust are widely distributed constituents of the desert environment, their potentially adverse effects must be kept constantly in mind in designating military equipment and be specifically evaluated in testing such material for its suitability for operation in the desert.

---

*The Indus valley was much wetter and highly vegetated, as has been confirmed by pollen studies showing open woodland species, grasses and shrubs some 5000 BP. After the Pleistocene (end of the last "Ice Age"), about 12,000 BP until about 9,000 BP, there developed a "Climatic Optimum" of greatly more extensive rainfall and temperate climate with extensive vegetative growth in many of the present desert areas. Although the Sahara region is an ancient desert (Mesozoic 150 million years BP) it has been intermittently verdant. During this last climatic optimum period, for instance, the central Sahara had developed grasslands with groves of Aleppo Pine, olive, cypress, juniper, and laurel with mixed oak, cedar forests, elm, linden, and maple in the highlands. Rivers were cut through the rocks where prehistoric men left pictographs in shallow caves. By 5,000 BP, however, the Sahara was virtually as it is today. Some several thousand year old cypresses are still to be found growing in the Tassili n-Ajjer mountains but no young trees. A similar cycle occurred in the western desert regions of North America. A second "Little Climatic Optimum" of lesser extent occurred during the period of 700-1200 AD, as is evidenced in a number of present desert areas as well as in more humid temperate regions by increased vegetative growth. It was during this latter period that much pueblo building and agricultural activity in the southwestern regions of the present USA occurred. Declining rainfall since that time, coupled, perhaps, with increased human activity in changing the vegetative cover in much of the world, has resulted in expansion of the deserts of the world.

At present, world population in these areas is estimated (1974) to be as shown in the following table.

ESTIMATES OF ARID LANDS POPULATIONS BY REGIONS
$(\times 10^6)$

Region	*Total*	*Urban*	*Farming*	*Stock Raising*
Mediterranean	106.8	42	60	4.2
Sub Saharan	75.5	11.7	46.8	17.0
Asia & Pacific	378.0	106.8	260.4	10.3
N. America	68.1	33.7	29.3	3.1
TOTAL	628.4	194.2	397.1	37.1
	(31%)	(63%)	(6%)	

Total World population (1974) 3.85×10^9 (est.)
Arid lands population: 16% of World Total

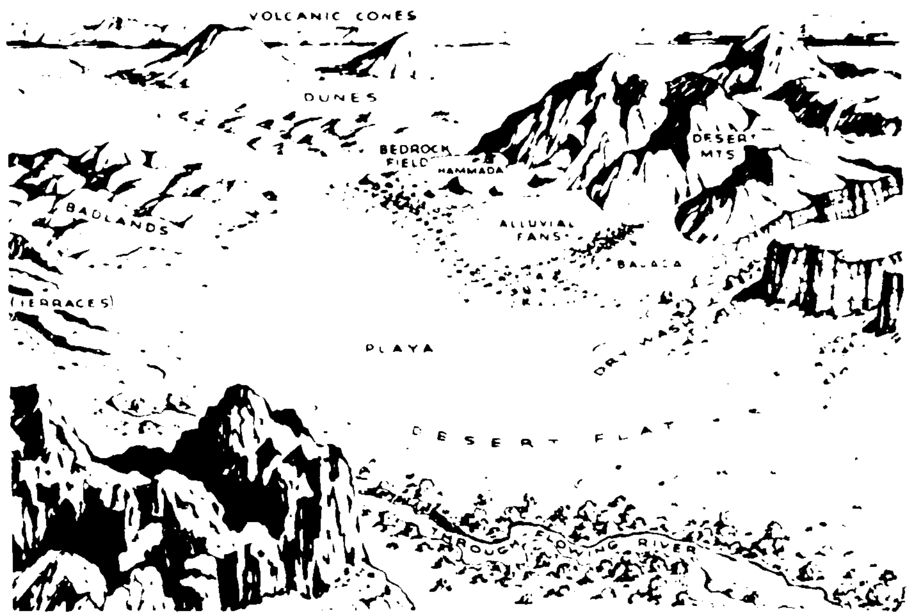


FIGURE II-3. TEN TYPES OF TERRAIN COMPRISING ALL WORLD DESERT AREAS

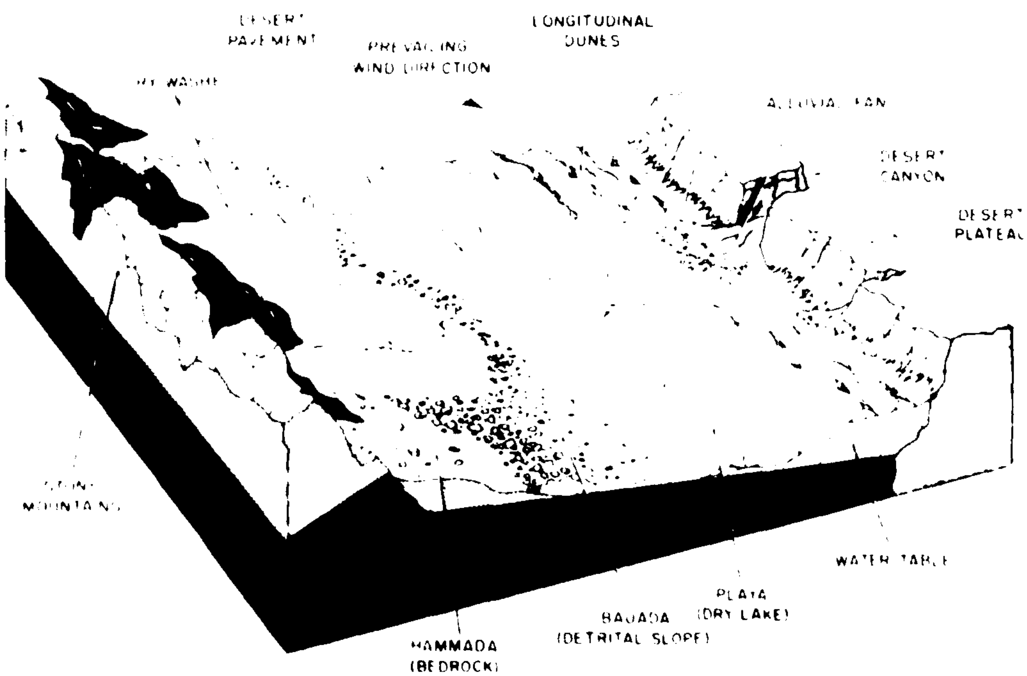


FIGURE II-4. TYPICAL DESERT TERRAIN STRUCTURES

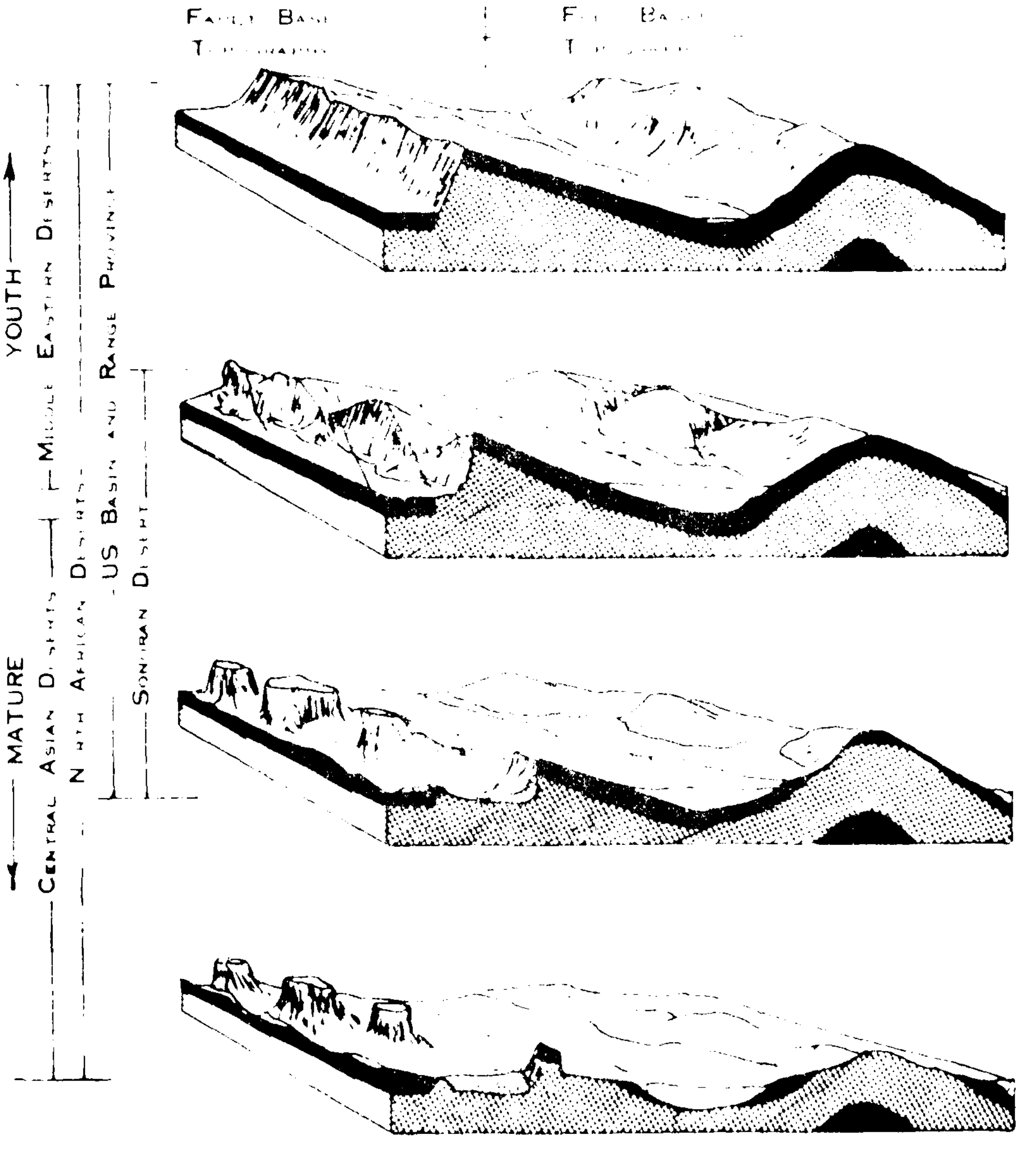


FIGURE II 5. STAGES IN DEVELOPMENT OF DESERT LANDSCAPES

Table II-1 includes climatic classifications for the deserts of the world, but for purposes of materiel design or operation, more specific criteria are needed. In the following discussions, detailed limits of desert characteristics will be presented. All of these data, taken from tabulations found in reference sources, are consolidated here to facilitate their availability, but it is highly recommended that the referenced sources be consulted for in-depth understanding of their derivation, constraints, and effects. Although AR 70-38 establishes the climatic criteria limits that materiel must meet, the data in the following tables provide a comprehensive view of the balance between those factors and may provide support for the emphasis (or deemphasis) of certain factors in a specific equipment item design.

5. Desert Terrain Classification

Deserts are composed of a great variety of terrain types or component terrain structures. These components can be gathered under certain broad headings for descriptive purposes. These include mountains, badlands and hills, fans and washes, desert flats and plains, and sand dunes and fields. Each heading is discussed in more detail below. The reader who is interested in quantitative descriptions and possible further breakdown is referred to the physiographic landscape classification used by the Corps of Engineers Waterways Experiment Station (WES), Vicksburg, Mississippi, and other similar terrain and geomorphic studies.

The WES landscape classification is based on a four-digit code. These four digits can be used to describe either component or gross landscape, Figure II-6. The first digit describes the characteristic plan profile as shown in Figure II-7. The second, third and fourth digits describe the slope occurrence, characteristic slope, and characteristic relief, respectively, Table II-3.

Many of the world's deserts have been mapped by WES in terms of these factors. These maps are available for reference and specialized planning.

a. *Characteristic Plan Profile*

The characteristic plan profile is the most commonly found plan profile within a region. It may be either gross or restrictive. A gross plan profile is one that can be subdivided into two restrictive component plan-profiles, each exhibiting relief of a lower order than the gross plan-profile. Random sampling with circles 35 miles (56 km) in diameter is used in determining the gross profile. Random sampling with circles 1 mile (1.6 km) in diameter is used to determine the restrictive plan-profile. Local relief of less than 10 feet (3 m) is not considered.

b. *Representative Plan Profile*

Each of the block diagrams (Figure II-7) illustrates a landscape representative of a specific plan profile type. It should be emphasized that, within the defined limits of each type, a wide variety of landscape configurations are possible.

B. EFFECTS OF DESERTS ON MATERIEL

1. General Effects

It is of interest to the designer, as well as the user of military equipment, to know how the desert environment may be expected to affect specific materials and mechanisms, particularly inasmuch as adverse effects may be encountered.

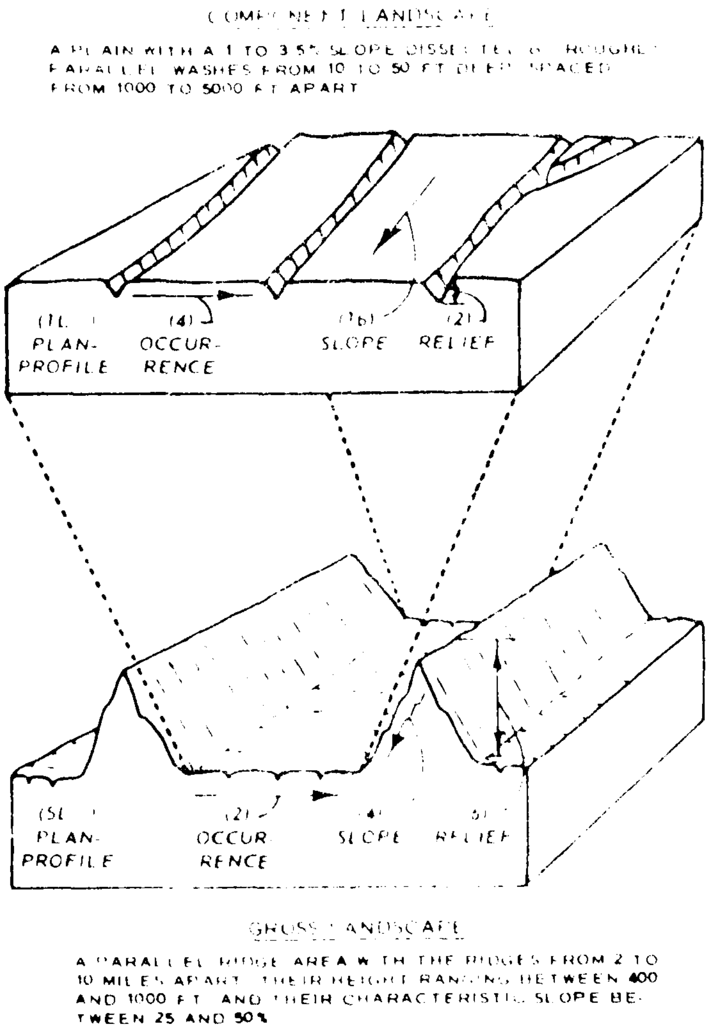


FIGURE II-6. LANDSCAPE CLASSIFICATION CODING (WATERWAYS EXPERIMENT STATION TERRAIN CLASSIFICATION SYSTEM)

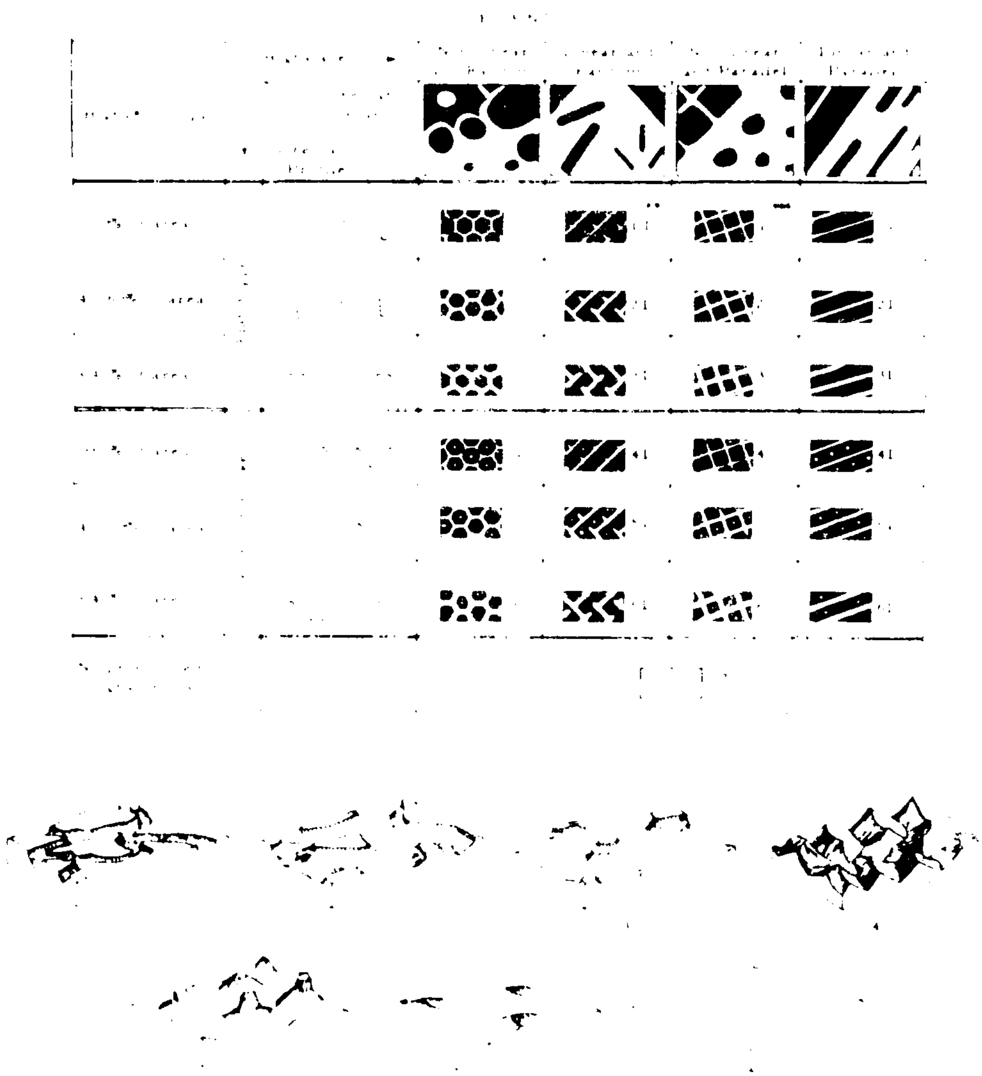


FIGURE II-7 CHARACTERISTIC PLAN PROFILE CODING

TABLE II-3 TERRAIN FACTOR CODING

Factor Code		Factor Description: Slope Occurrence (per 10 miles) (second digit)					Characteristic Slope (deg) (third digit)							Type 1 / Characteristic Relief (ft) (fourth digit) / Type 2						
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	x													x						
1a							x													
1b								x												
2		x							x						x					
3			x							x						x				
4				x							x						x			
5					x							x						x		
6						x							x						x	
7																				x

Many of the world's deserts have been mapped by WES in terms of these factors. These maps are available for reference and specialized planning.[22]

Some of the environmental factors characteristic of desert operation have immediate effect on the operation of equipment: differential expansion of component parts causing binding or interference, clogging of dust filters, and overheating of components; other effects may be cumulative: accelerated aging caused by UV exposure, accelerated fatigue caused by higher temperatures, and softening of plastic components. Many deleterious effects are synergistic—i.e., the result of combinations of environmental factors that appear in nature. Many factors may, on the other hand, be considered as independent of each other even though they may be concurrently experienced—e.g., high solar radiation and high wind velocity or high air temperature and heavy dust concentration.

Table II-4 delineates areas of degradation that may occur in component systems, as affected by adverse desert factors or induced environmental conditions. Table II-5 indicates how specific types of materials may be adversely affected by environmentally induced physical or chemical conditions—e.g., rainfall or high humidity inducing biochemical corrosion of surface materials or sunlight (UV) causing hardening of plastics or fading of fabric dyes.

Finally, Table II-6 lists the principle effects and corresponding deficiencies induced by specific, singular environmental factors characteristic of desert operations. The majority of these effects and failures are relatively straightforward with respect to cause and effect. The inclusion of high relative humidity and rain among desert environmental conditions should not be considered illogical. Rain does occur in desert areas, frequently in torrential, even though short-lived storms, with consequent flooding, deep mud, salt marshes with salt spray, and short-lived high humidity. Atmospheric moisture can result in water condensing and collecting in enclosures when temperatures at night go below the dewpoint. Humidity, with resulting dew formation, is generally not a problem on exposed, open surfaces, as may be observed from 50-year-old tin cans along desert roads, but it may be a problem in poorly ventilated chambers, such as fuel tanks; storage tanks; flotation chambers; metal cabinets (particularly in storage); and similar enclosed air spaces that "breathe" with changes in air temperature.

More detailed discussion of the effect of adverse levels of these environmental factors may be found in other data sources.[12,14,20,23,26] It is strongly recommended that users of this document familiarize themselves with that information because it is not considered feasible to repeat such a voluminous, complex

TABLE II-4. EFFECT OF ENVIRONMENTAL FACTORS[12*]

Major effect	Causes
Mechanical damage (deformation, fracture, fatigue, loss of strength, change of state, change of viscosity for liquids)	Temperature, humidity, water, rain, wind loading and air pressure, blowing sand and dust, terrain (shock, vibration, impact), macrobiological organisms, shock, vibration, acceleration, solar radiation
Chemical damage (deterioration, corrosion, spoilage)	Temperature, humidity, fog, salt fog, salt water and spray, rain, ozone, air pollutants, microbiological organisms
Mobility reduction (embedment, trapping, loss of traction)	Ice, snow, mud, wet salt flats, sand, relief (topography), rocks and boulders, vegetation, grade, water, step function interfaces in the terrain
Interference	
Optical (reduction of visibility, loss of communications)	Rain, snow, mirages, darkness, terrain, clouds, dust storms, vegetation, water (covering terrain), countermeasures
Electromagnetic (nonoptical)	Lightning, terrain, rotating machinery, electromagnetic pulses from nuclear weapons, electrostatic discharge, communication (radio and television sources, microwave sources, radar, laser, transmission lines, industrial equipment)
Audio	Gunfire, explosions, rotating machinery, vibration of materiel, impact or shock of materiel, thunder, traffic, construction, exhaust noise from engines

*Amended

TABLE II-5. MATERIAL DETERIORATION AGENTS[12*]

Material	Agent
Inorganic	
Metals	Mechanical erosion, chemically induced corrosion, electrolytic processes, age hardening, stress deterioration, expansion, contraction
Glasses	Actinic processes, physical and chemical weathering, erosion, abrasion, microbiological erosion
Organic	
Rubber	Oxidation (ozone), loss of plasticizer, high temperature (continued polymerization), microbiological attack, stress deterioration
Plastics	Chemical attack (solvent vapors), actinic processes, hardening, fading, microbiological attack, mechanical stresses, softening, continued polymerization
Oils and greases	Chemical dissociation, microbiological attack, evaporation
Wood (cellulose)	Biological attack, warping, splitting, delamination, biological attack, actinic processes, fading, thermal deterioration
Leather	Mechanical abrasion, thermal deterioration (dessication, aging, cracking), biological attack (bacterial, animal, fungal)

*Amended

TABLE II 6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS[12*]

Environmental factor (AR 70 38 Limit)	Principal effects	Typical failures induced
High temperature (125 F operation 160 F storage)	Thermal aging Oxidation Structural change Chemical reaction	Insulation failure alteration of electrical properties alteration of physical properties hardening cracking
	Softening melting and sublimation Viscosity reduction and evaporation Physical expansion	Structural failure Loss of lubrication properties Structural failure increased mechanical stress binding increased wear of moving parts
Low temperature (-40 F storage -25 F operation without aids)	Increased viscosity and solidification Ice formation Embrittlement	Loss of lubrication properties Alteration of electrical properties Loss of mechanical strength cracking fracture
	Physical contraction	Structural failure increased wear of moving parts
High relative humidity (Dew condensation 100% RH	Moisture absorption water collecting in poorly ventilated enclosures Chemical reaction Corrosion Electrolysis Biological propagation Bacterial Fungal	Swelling rupture of container physical breakdown loss of electrical strength loss of mechanical strength interference with function fuel contamination Loss of electrical properties Increased conductivity of insulators
Low relative humidity	Dessication Embrittlement Granulation	Loss of mechanical strength Structural collapse Alteration of electrical properties dusting
High pressure	Compression	Structural collapse seal penetration interference with function
Low pressure	Expansion	Fracture of container explosive expansion alteration of
	Outgassing	electrical properties loss of mechanical strength
	Reduced dielectric strength of air	Insulation breakdown and arc over corona and ozone formation
Solar radiation	Actinic and physico chemical reactions Embrittlement	Surface deterioration differential expansion alteration of electrical

TABLE II-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Cont'd)

Environmental factor AR 70-38 Limit	Principal effects	Typical failures induced
	Heating (directional)	properties, discoloration and fading of materials, ozone formation
Sand and dust	Abrasion Clogging	Increased wear Interference with function etching of vision devices, blocking moving elements alteration of electrical properties, erosion of surface coatings
Salt Spray (including salt dust in coastal areas and salt beds	Chemical reactions Corrosion	Increased wear, loss of mechanical strength, alteration of electrical properties, interference with function
	Electrolysis	Surface deterioration, structural weakening increased conductivity
Wind	Force application	Structural collapse, interference with function, loss of mechanical strength
	Transport of materials	Mechanical interference and clogging, abrasion accelerated
	Heat transfer Loss (low velocity) Gain (high velocity)	 Accelerated low temperature effects Accelerated high temperature effects
Rain	Physical stress Water absorption and immersion Biological propagation Bacterial Fungal Erosion Corrosion Mud formation	Structural collapse Increase in weight Structural weakening Accelerates cooling Electrical failure Removes protective coatings, structural weakening, surface deterioration Enhances chemical reactions Mobility reduction
Water immersion	Corrosion of metals Chemical deterioration High pressures (13 lb at 30-ft depth)	Structural weakness, seizure of parts, contamination of products Dissolving out and changing of materials Mechanical damage

TABLE II 6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Cont'd)

Environmental factor (AR 70 38 Limit)	Principal effects	Typical failures induced
Biological		
Insects and bacteria	*Penetration into equipment*	Blockage of small parts meters etc
Animals	Nibbling by animals termites insect larva and adults	Damage to plastic cables or other organic insulating materials causing shorts structural failure of wood cloth and paper elements
Fungi	Growth of molds hyphae	Damage to optical equipment leakage paths in high impedance circuits blockage of small parts meters etc breakdown of mechanical strength of all organic materials disintegration of wood paper and cloth
Temperature shock (sudden major temperature changes)	Mechanical stress	Structural collapse or weakening binding of moving parts seal damage
High speed particles (nuclear irradiation)	Heating	Thermal aging chemical reaction polymerization
	Transmutation and ionization	Alteration of chemical physical and electrical properties production of gases and secondary particles
Ozone	Chemical reactions	Rapid oxidation fading
	Crazing cracking	Alteration of chemical physical and electrical properties
	Embrittlement	Loss of mechanical strength cracking
	Granulation	Interference with function
	Reduced dielectric strength of air	*Insulation breakdown and arc over*
Explosive decompression	Severe mechanical stress	Rupture and cracking structural collapse
Dissociated gases (exhaust gases missile and ammunition propellant gases)	Chemical reactions	Alteration of physical and electrical properties
	Contamination	
	Reduced dielectric strength	Insulation breakdown and arc over
Acceleration	Mechanical stress	Structural collapse
Vibration	Mechanical stress	*Interference with function increased wear structural collapse*
Magnetic fields	Induced magnetization	Interference with function
Electromagnetic Radiation (RF to microwave)	Induced currents	Alteration of electrical properties heating

discussion here, even though its understanding is important to the subject of materiel testing in the desert environment.

Irrespective of the criteria characteristic of desert environments discussed in the previous section, the limits of these factors as delineated in AR 70-38 are controlling for the determination of the performance of Army materiel in the desert environment and must be observed. The AR 70-38 limit values for those environmental factors covered are shown in Table I-4 and Section I.B to indicate levels of these factors that must be met without adverse effects on the equipment under consideration. Other factors not included in the primarily climatological concerns of AR 70-38 are those relating to topographical or terrain effects, such as mobility of vehicles—emplacement of artillery pieces—and preparation and concealment of storage sites (camouflage) or artillery and rocket warhead impact effects, in which the geometry or physical characteristics of the soil are of major importance.

In general, most vehicular problems encountered in the desert environment are caused by sand and dust and by extremely high temperatures. Deep sand and powdered clay and the infiltration of sand, dust, and grit cause personnel problems as well as problems with vehicle mobility and the operating mechanisms of vehicles, Figures II-8 and II-9.

Pneumatic tires for wheeled vehicles and solid rubber road wheels for tracked vehicles are seriously affected by heat build up. They frequently experience blowouts or chunking (tread separation) when operated at higher speeds on hot paved and gravel roads and are readily cut by sharp edged rocks when operated off roadways, Figures II-10 through II-14.

Transmissions and engines fail much more rapidly than in temperate uses because of increased power requirements, as well as the higher temperatures. Batteries deteriorate more rapidly because of the high temperatures. Contamination from fungal and biological growths and particulate matter in the form of dust and grit is a serious problem, particularly with fuels and lubricants.

The presence of bacterial or fungal contamination is seldom expected in the dry environments typical of desert regions. However, in poorly ventilated enclosures, such as fuel tanks, oil reservoirs and the like, moisture condenses from the air inside these vessels when nighttime temperatures drop below the dewpoint. Such moisture may not be re-evaporated during the day because of the lack of ventilation and builds up sufficiently to provide an environment highly conducive to bacterial and fungal propogation. Numerous instances of internal corrosion of fuel line blockage, injector blockage, and lubricating failure have been traced to this source.

Engine problems in diesel-powered vehicles at YPG, in one instance, revealed the following organisms to be present in the fuel and assumedly originating from the vehicle fuel tanks. It must be noted that water must be present for these organisms to be viable:[27]

Bacterium *Pseudomonas* (alcaligines, pseudomallei, aeruginosa, cepacia)
Bacterium *Baccilus*
Fungus *Scopulariopsis*
Fungus *Aspergillus*
Fungus *Penicillium*
Fungus *Fusarium*
Fungus *Candida*

FIGURE II-8. PROTECTIVE RESPIRATOR AND GOGGLES REQUIRED FOR OPERATION IN EXTREME DUST ENVIRONMENT

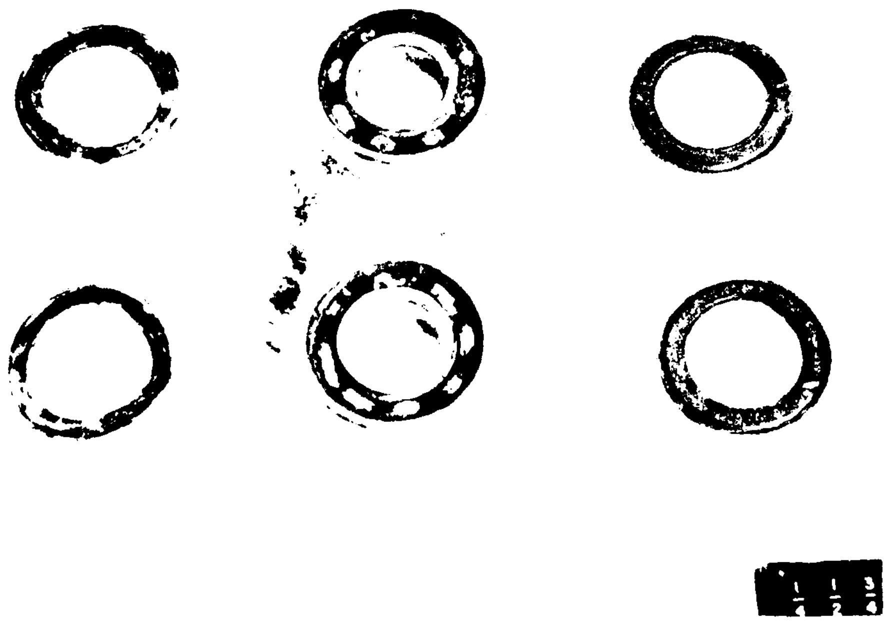


FIGURE II-9. TANK THROTTLE LINKAGE BEARINGS -- CONTAMINATED WITH DUST; CAUSED LINKAGE TO BIND

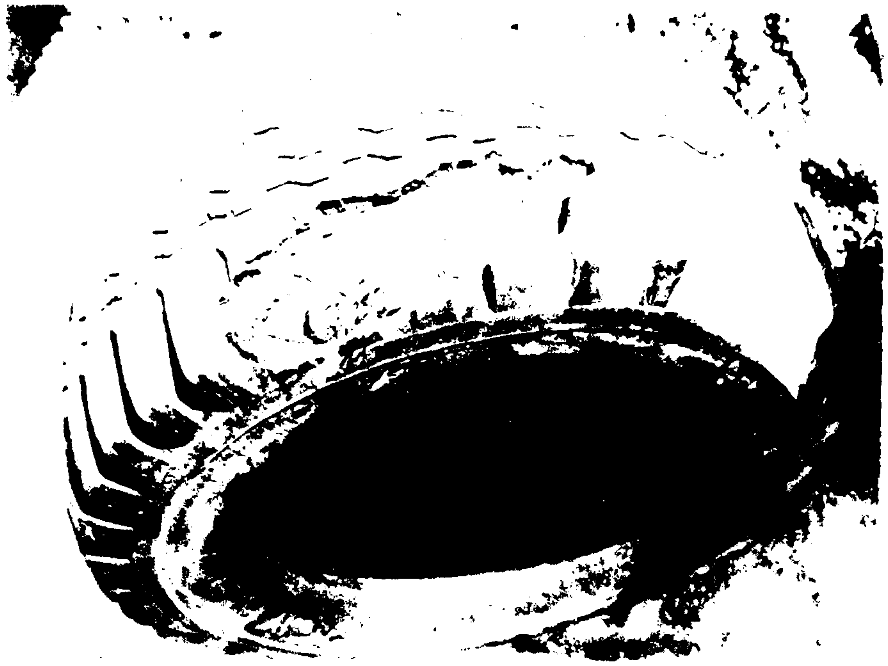


FIGURE II-10. TREAD SEPARATION FAILURE

FIGURE II-11. TIRE CARCASS FAILURE RESULTING FROM HIGH LOAD, HIGH SPEED AND HIGH AMBIENT AND ROAD SURFACE TEMPERATURES

FIGURE II-12. TRACK PAD BLOWOUT

FIGURE II-13. SECTIONED TRACK PAD – INTERNAL DAMAGE (BLOWOUT) CAUSED BY HIGH TEMPERATURE OPERATION

FIGURE II-14. TRACK PAD—DELAMINATION OR BOND FAILURE CAUSED BY HIGH TEMPERATURES DURING OPERATION

Fungus *Alternario*
Actinomycetes

Organisms of this type, which are commonly associated with soils, can synthesize chemical compounds that are corrosive to metal parts. They are generally restricted to the water-fuel interface. There is some possibility that water in fuel tanks may result from rain or vehicle washing or stream fording, but these are unlikely in desert operations; the above mentioned condensation of airborne moisture is considered to be the predominant factor.

Forced ventilation is needed to provide clean, cool air in enclosed spaces and to maintain proper relative humidity for human comfort. Ventilation equipment frequently does not completely filter fine sand and dust from intake air, resulting in damage to equipment and to personnel, especially in moving vehicles.

Problems of photographic equipment in desert regions are those of high temperatures, which cause changes in processing variables and rapid deterioration of both unexposed and exposed film, together with dust infiltrating cameras and film processing equipment.

Shelter in desert regions is not as critical to survival as in artic regions; yet, in many cases it must be provided for protection from heat and high solar radiation. Problems with electronic equipment in desert operations involve the high temperatures induced by solar radiation when added to normal operating heat sources. Hot spots develop around operating components that dissipate heat and are further aggravated by direct heating by solar radiation. Fine sand and dust contribute problems by infiltrating mechanical moving parts, causing excessive wear, interference, and jamming of equipment. Generally, in desert areas, electronic equipment must be provided dust-free, cooled air to maintain operational reliability. Table II-7 presents some of the difficulties produced by the desert environment on various types of ground support equipment.

Summer desert tests conducted at the Yuma Proving Ground on the performance of vehicles and equipment revealed many problems resulting from severe mechanical and thermal stresses imposed by desert operating conditions. Although solutions for these problems were, in general, not difficult, the equipment would not have performed satisfactorily in the desert without corrections for these defects being revealed by the test programs.

2. Specific Effects

a. *Vehicles*

(1) Mobility

Mobility testing of wheeled vehicles indicates that decreased tire pressures increase vehicle mobility, enable vehicles to climb steeper grades and longer slopes, increase tractive effort, and decrease resistance to towing in soft soils and loose sand. In addition, comparative tests between single- and dual-tired vehicles of similar types reveal the superiority of vehicles equipped with large, single tires in traversing deep, loose, sandy terrain. In tests at Death Valley, California, the mobility of the T43E1 tank was hampered by the protruding gun striking the ground when traversing gulleys, not uncommon in desert areas. This can be a problem with vehicles carrying long-barreled weapons in either the "ready" or "stowed" modes.

(2) High Temperatures and Related Problems

Most vehicle cooling systems function satisfactorily during desert cooling tests under moderate stresses consistent with normal road load conditions. With more rigorous test conditions, the cooling systems generally do not function satisfactorily. The cooling systems of tracked vehicles are generally adequate for moderate test conditions but not for more rigorous conditions.

Table II-8 summarizes the full-load cooling performance of a cross-section of vehicles tested prior to 1973. It will be noted that many show excessive temperatures under this operating regime. In most instances, these inadequacies were of degree rather than outright failures; i.e., exceeding cylinder head, transmission, or gear lubricant temperatures when operating at full output at very low road speeds at limiting ambient air temperatures. Lubricant breakdown results with sludge formation, reduced lubricity, and load carrying ability, Figure II-15. Higher road speeds, even at full throttle, would bring these temperatures down as would also reduced road load, i.e., reduced throttle. In most instances, these conditions were rated as shortcomings rather than deficiencies.

The M60A1 tank showed transmission oil temperatures would exceed the 300°F (149°C) limit at ambient air temperatures in excess of 115°F (46°C) at 2.7 mph in low range. In another test of the XM1 tank, using fuel having a flash point of 145°F (63°C), fuel tank temperatures of 159°F (71°C) were measured at 104°F (40°C) ambient temperature. When fuel temperature is above the flash point, volatile gases are present in the fuel tank and would be released in the event the filler cap were opened. This would create the possibility of a fire if an ignition source were present and negates the inherent advantage of distillate fuel over gasoline in preventing fuel fires in combat vehicles.

TABLE II-7. DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT BY VARIOUS TYPES ON GROUND SUPPORT EQUIPMENT

Material	Environment effect	Remedy
Electronic equipment	Dust and sand penetrate defective seals and packings. Some greases fail at high desert temperatures. Shock and vibration cause damage due to rough terrain. Differential expansion of plates, components and breaks [illegible].	Encapsulation. Hermetic seals, use of packing and greases specified for desert use, vibration and shock proof mountings, weight reduction and better structural design of components.
Components	Fan [illegible] of [illegible] equipment [illegible] are reduced by the high atmospheric temperatures and ever present dust, which [illegible] in addition to high temperatures generated within the equipment itself.	Positive heat dissipation, dust exclusion, encapsulation.
Shelters		
Wooden shelters	Buckling of large wood or steel sections. Warping, splitting and delamination due to drying out.	Provide sufficient allowance for expansion and contraction. Use seasoned lumber and exterior grade plywood.
Painted Surfaces	Wind born sand abrades painted surfaces.	
	The high daytime and low nighttime temperatures cause materials to expand and contract in a continuous cycle. This causes premature failure of brittle paint films and glazed joints.	Repaint every 1 to 3 yr, depending on the quality and type of paint. Use abrasion resistant paints if available.
	High UV ray exposure causes accelerated aging and fading of paints.	
Ventilation	Inside air temperature of enclosed spaces may be 40 to 60° F above ambient. The fact that ambient temperature may go to 130° F makes this problem critical. Relatively dry air can become saturated at dewpoint temperatures at night and generate water which may not be re-evaporated in poorly ventilated spaces.	Ventilation should be provided, but adequate airflow will be complicated by the need for filters due to presence of dust and sand.
Foundations	In windy areas, sand may be blown away from beneath foundations.	In general, excellent foundations are possible in the desert. Use of coarse gravel will prevent wind excavation around foundations.
Masonry and earth	Stone and mud bricks are the only available natural building materials.	There are few climatic and environmental factors that promote undue deterioration in masonry materials in the desert. When properly constructed, earth shelters may last for a very long time in dry climates.
Roofs	Intense solar radiation heating makes indoor temperature extremely high unless adequate roof insulation is provided.	Buildings should have roof insulation, if possible, either by double roofs or suitable insulating materials, or both. Use light colored roofing materials, if feasible.
Lubricants	Breakdown of lubricants due to excessive temperatures. Shock and vibration permit sand and dust to pass filters, screens and seals into lubricants, causing excessive wear on moving or bearing surfaces.	Frequent inspection, cleaning, and enhanced maintenance are required to keep dust and sand out of lubricants.
	Air cleaners quickly become clogged, resulting in rapid cylinder and ring wear from abrasive sludge in the lubricating system.	Service air cleaners as frequently as required by local conditions. Use prescribed grades and types of lubricants.

TABLE II 7. DIFFICULTIES [illegible] VARIOUS TYPES
[illegible] GROUND [illegible]

Materiel	[illegible]	[illegible]
Electrical power generating equipment		
Gasoline and diesel [illegible] generating equipment	[illegible]	[illegible] protected [illegible]
	[illegible]	[illegible] heaters [illegible]
Generators and motor generators	[illegible]	[illegible] may be ne[illegible] vehicle [illegible]
	[illegible] increase wear	[illegible]
	[illegible]	[illegible]
Dry cell batteries	[illegible]	[illegible] feasi[illegible]
Wet cell batteries	[illegible]	[illegible] storage [illegible] 4 [illegible]
Vehicles		
Self propelled	[illegible]	Sealing, filtering, and screening where possi[illegible] and maintenance should be more frequent and periodic with shortened intervals for vital parts. Materials and [illegible] be selected to withstand the ad[illegible] expected.
	[illegible] steering systems [illegible]	Vehicles must be designed to meet terrain re[illegible]
Power plants and chassis components	[illegible]	[illegible] adequate capacity to meet [illegible] Operate engine within or below [illegible] maintenance may be [illegible]
	[illegible]	[illegible] should be located [illegible] free flow of air and away from the heat [illegible] may be insulated. Pro[illegible] submerged fuel pumps.

TABLE II-7 DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT BY VARIOUS TYPES ON GROUND SUPPORT EQUIPMENT (Cont'd)

Materiel	Environmental effect	Remedy
Vehicles (Cont'd)		
Power plants and chassis components (Cont'd)	Engine attachments are subjected to heavy stresses induced by rough desert terrain. Brackets for oil filters, exhaust piping, mufflers and other auxiliaries, including instruments and panels, have failed.	Improve design of parts and supporting structures to provide greater shock strength and longer life.
Transmission and Gearing	Filler plugs for transmission and transfer cases are often difficult to remove and service particularly when hot. Frequent shifting of gears necessitated by operation in difficult desert terrain and deep sand causes heating and accelerated wear.	Plugs should be designed to provide ease of removal and replacement. Automatic transmissions should be designed to meet desert stresses and shift mechanisms should operate easily for frequent use.
Rubber components	Rubber, natural and synthetic, deteriorates when exposed to heat, light or ozone, affecting mountings, seals, and tires. Tire life is short in the hot, rugged, sandy terrain because of abrasion and reduced strength. Sand and gravel thrown from tracks or wheels abrades chassis elements.	Rubber materials should be selected for the expected conditions. Chassis components should be located to avoid material thrown up by running gear.
Traction	The deep sand and powdered clay of the desert give poor traction for wheeled vehicles. Powering wheels dig in under heavy loads.	The use of large diameter, single, partially inflated tires provides more satisfactory traction than multiple tires.
Brakes	Sand and dust cause excessive wear.	Brakes must be shielded to prevent entry of sand and dust.
Cooling systems	Cooling systems become clogged with rust. Crankcase develops sludge. Bearings corrode. Exhaust valves stick.	Frequent inspection followed by necessary maintenance and use of proper materials.
Lubricants	Heavy dust may require changing oil cleaners very frequently and lubricating oil at shorter than normally prescribed intervals. In high atmospheric temperatures, grease may be thrown out of bearings and may become unstable in storage.	Engine sludge can be prevented with prescribed lubricants and maintenance; bearing corrosion by the use of the prescribed lubricants. Frequent inspection and maintenance using proper, prescribed lubricants with special attention to seals, covers, and packing is required.
Trailers (personnel housing)	The effect of high temperatures on the ability of personnel to work efficiently is the limiting factor of trailer operation.	Air cooling systems, either permanently installed or external, are a necessity for maximum efficiency. Paint exterior surfaces with light colored, radiation reflecting paints to reduce solar heat absorption.
	Electronic components required to operate at high temperatures of about 165 F suffer a serious reduction in life.	
	Excessive wear of moving parts caused by fine sand and dust.	Provide and maintain high capacity air filters in the ventilating system.
	Vibration and shock induced by poor roads and rough terrain cause excessive damage to equipment items installed in trailers.	All attached and installed equipment should be shock mounted, encapsulated or otherwise designed to withstand high shock.

TABLE II 7. DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT BY VARIOUS TYPES ON GROUND SUPPORT EQUIPMENT (Cont'd)

Materiel	Environmental effect	Remedy
Spare parts (storage)	Tires and rubber parts suffer [illegible] cracks when exposed under strain	Tires and other rubber parts [illegible] should be wrapped or enclosed [illegible] [illegible] Rubber compounds [illegible] selected to avoid ozone cracking
	Unwrapped parts [illegible] contaminated with dust and sand	Keep parts packaged [illegible]
	[illegible]	Avoid exposure to direct sun rays

TABLE II 8. SUMMARY OF COOLING PERFORMANCE ON MILITARY VEHICLES — MAXIMUM TEMPERATURES RECORDED DURING FULL LOAD COOLING TEST ([illegible] PROVING GROUND)[28]

Vehicle Model	Vehicle Size Type	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Ambient [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M54A2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M151A1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM656	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] System	[illegible]
XM656	5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] System	[illegible]
XM656	5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM656	5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M54E3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]A2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M35A2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M113	APC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	Sheridan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M551	Sheridan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	Tank	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	Tank	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M60	Tank	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	Tank	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM[illegible]	Hawk [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M274	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M116	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VTP(X)12(F)	APC	4	[illegible]	[illegible]	[illegible]	243	[illegible]	[illegible]	[illegible]
XM706	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M[illegible]A1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
XM520E1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Temperature not stabilized [illegible]

L — Low
H — High
[illegible]
* — Not [illegible]

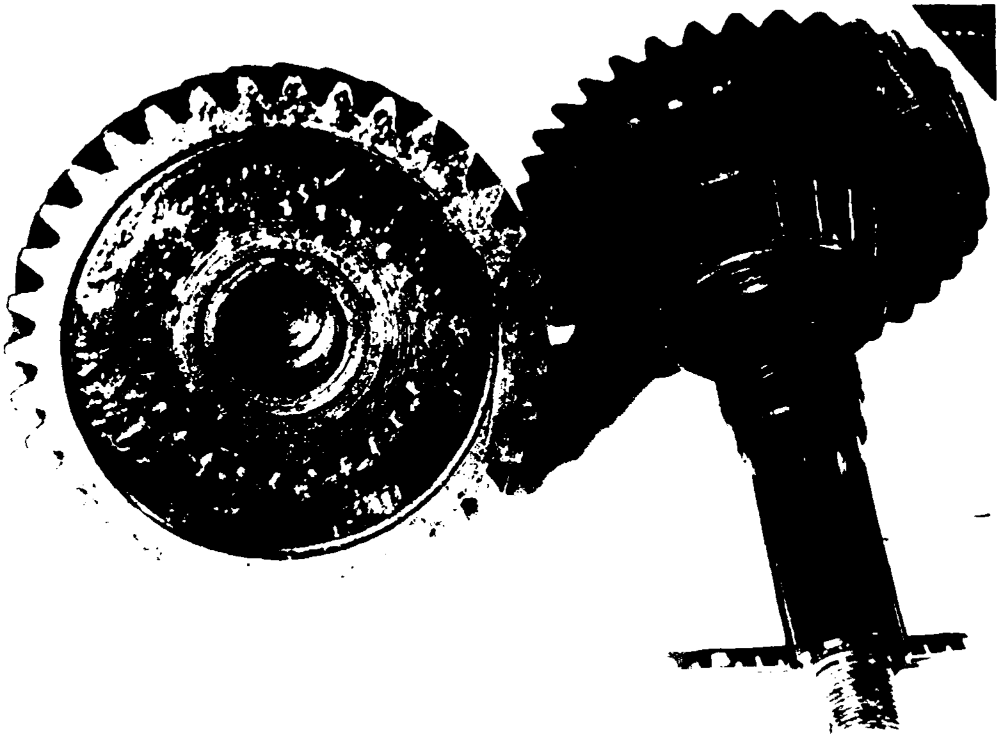


FIGURE II-15. DETERIORATED LUBRICANT DEPOSITS ON TRANSFER CASE GEARS AFTER 12,000 MILES AT HIGH AMBIENT TEMPERATURES

In one desert test, only a few types of gasoline-powered, wheeled vehicles equipped with engine-mounted, vacuum fuel pumps could be operated without vapor lock occurring. During another test, the only wheeled vehicle found acceptable at high temperatures was one equipped with a submerged-type electric fuel pump. In general, the replacement of the normal, external pump with a submerged-type pump eliminated vapor lock. Most main engines (gasoline) in tracked combat vehicles tested at Yuma appeared to be immune to vapor lock, but the auxiliary (gasoline-fueled) engines with which they were equipped experienced severe vapor lock and required major corrective treatment.

As of 1980, vapor lock problems have largely disappeared because of the use of diesel engines and submerged or in-tank fuel pumps. Gasoline is still prescribed as an alternate fuel for multi-fuel engines; however, the techniques developed for correcting these deficiencies in the past can be applied in any future developments. Further, such techniques must be considered not only for vehicular applications but for any engine-driven equipment, such as portable construction, pumping, air compressor, and power generator applications as well.

Tracked vehicles, particularly those with light-weight band tracks, are subject to track misguiding and breakage when operating in loose sand and rocky terrain if track adjustment is not properly maintained.

In a series of operational [environmental storage] tests on the M60 tank in 1973 [illegible] temperatures at various points inside the turret and on the outside surfaces of the vehicle, as shown in Figures II-16, and [II-17] were observed. Although materials would be relatively unaffected by these temperatures, serious [decline in] comfort, and increased degradation of performance could be expected of personnel having to remain in these vehicles under such operating conditions.

Sandblasting and entrance of sand and dust into crevices, particularly between moving parts, can cause excessive wear and jamming of the mating surfaces (Figure II-18).

Figure II-19 illustrates wear of track guide surfaces and chunking [illegible] tires of a road wheel from an M113 Armored Infantry Vehicle after some 2000 mi (3200 km) [illegible] ety of road and cross-country courses.

Heat damage to a brake wheel [cylinder] boot caused by high brake temp[eratures] [illegible] high ambient temperatures is shown in Figure II-20.

In the initial production test of the M901 improved (anti-tank) TOW Ve[hicle] [illegible] ments indicated problems with excessive heat, dust, and desert vegetation. Crew members stated they were glad they didn't have to keep hatches and ramp closed during weapon system operation. Heat [illegible]

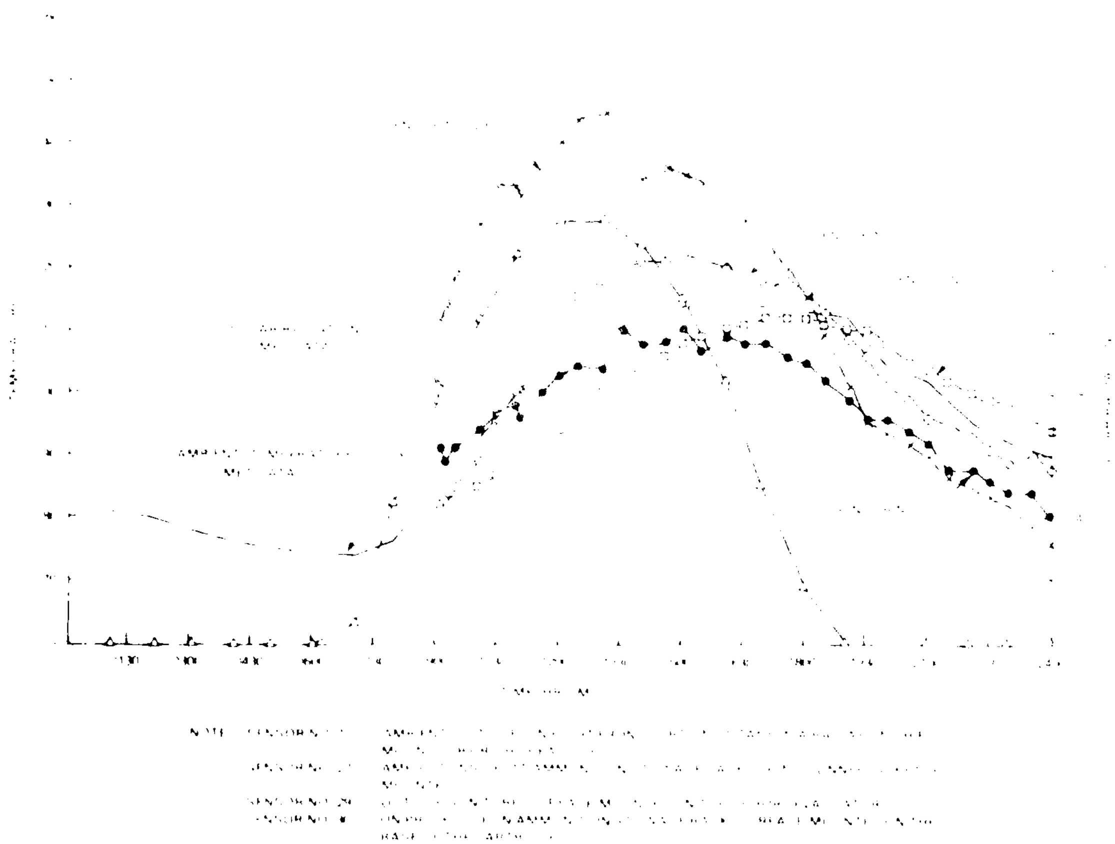


FIGURE II-16 HIGHEST TEMPERATURES (°F) AND SOLAR RADIATION (LANGLEYS) OBSERVED WITH THE M60 TANK DURING DESERT STORAGE CONDITIONS WITH THE HATCH OPEN 7 SEPTEMBER 1973

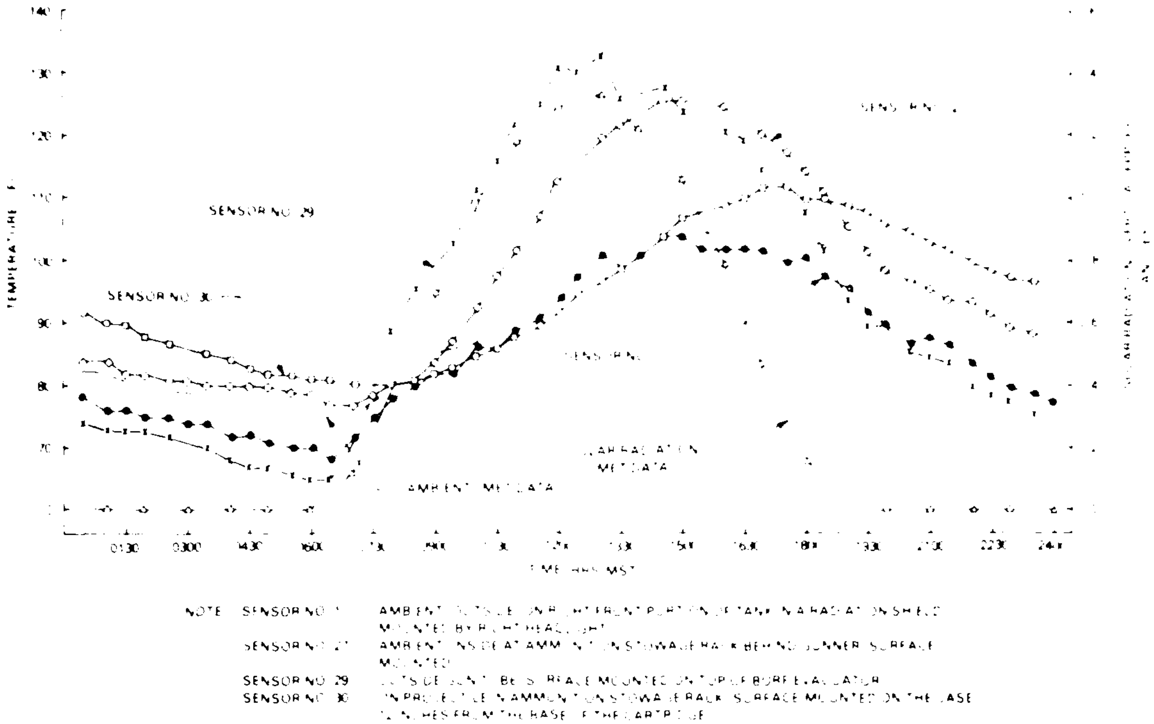


FIGURE II-17. HIGHEST TEMPERATURES (°F) AND SOLAR RADIATION (LANGLEYS) OBSERVED WITH THE M70 TANK DURING DESERT STORAGE CONDITIONS WITH THE HATCH CLOSED, 11 SEPTEMBER 1973

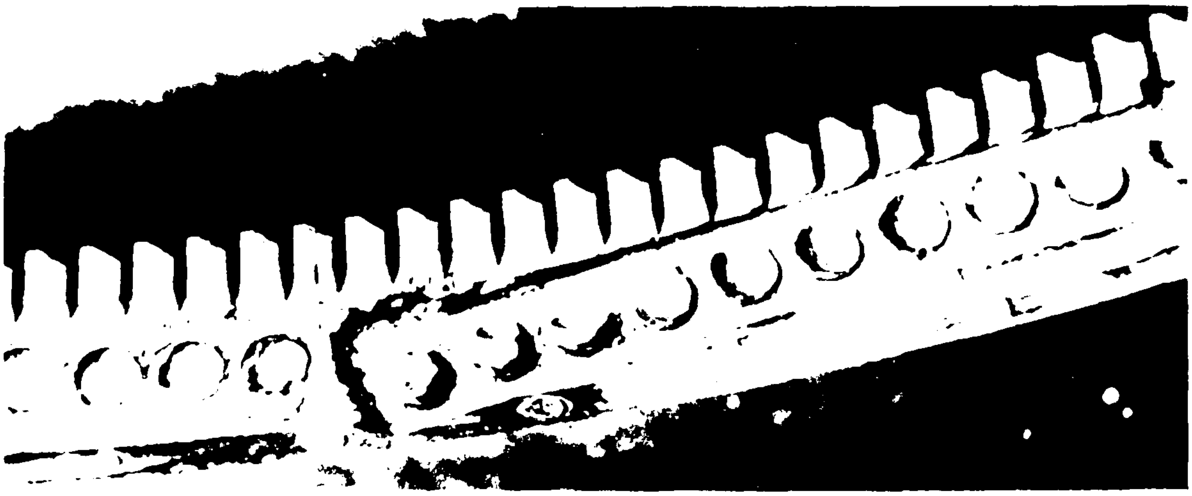


FIGURE II-18. TANK COMMANDER'S CUPOLA BEARING – ABRAIDED RACE AND PLASTIC BALLS FROM DUST INFILTRATION; PREVENTED CUPOLA ROTATION

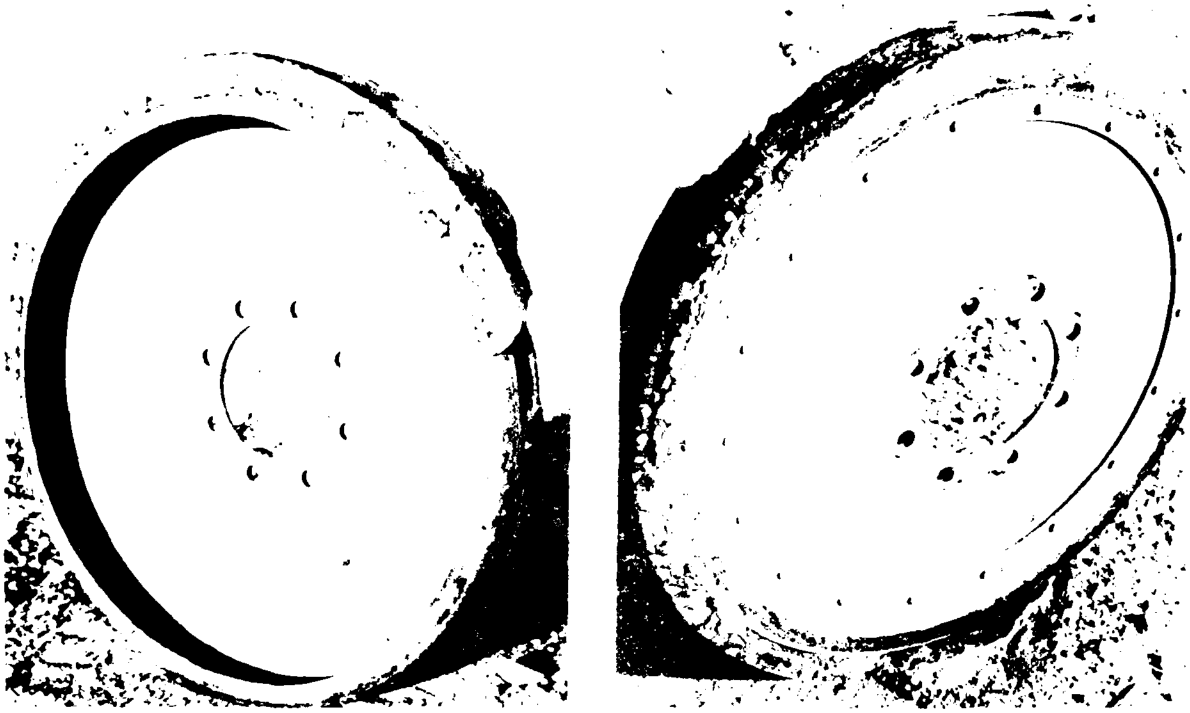


FIGURE II-19. ROADWHEEL DAMAGE (TIRE SEPARATION, CHUNKING AND TRACK GUIDE WEAR) AFTER OPERATION ON LEVEL CROSS-COUNTRY COURSE

FIGURE II-20. BRAKE WHEEL CYLINDER BOOT – SOFTENED AND TORN DURING HIGH TEMPERATURE OPERATION

weapon system, added to normal vehicle heat, would make conditions intolerable, if closed up. Dust jammed the actuator valve of the nightsight cooling bottle, putting the sight out of operation. Dust jammed latches on the cargo hatch and caused the locking pin to bind. Desert vegetation knocked a grenade storage box off the side of the vehicle.

An articulated construction vehicle having a power section and alternate work sections, "Family of Military Engineer Construction Equipment" (FAMECE), experienced a number of deficiencies in test operations on the dust course and roads:[32]

- Sand, dust and gravel on the coupler frame housing and lock ring sliding surfaces interfered with lock ring rotation.
- Cab floor temperatures, extrapolated to 125°F (52°C), reached 224°F (128°C) under full load operations; 153°F (68°C) under road load; and 190°F (88°C) during earthmoving operations.
- Moisture condensation in the compressed air system caused rusting of the quick disconnect fittings (air check valves) and failure to close. Consequent air loss caused brake failure.

Most cooling tests are conducted on the dynamometer course (maximum loading conditions) or cross-country or on the highway (road-load conditions). An interesting addition to such operation is that amphibious vehicles, such as the U.S.M.C. LVTP7, Figure II-21, must cool adequately while swimming in water at 95°F (35°C).

Tests are run on the dust course both with another vehicle closely in front of the test vehicle and with the test vehicle alone to determine the efficiency of engine air cleaners, Figures II-22, II-23 and III-17. In such an air cleaner test, with no lead vehicle, an M60A1 tank, which can obtain its engine intake air from the crew compartment, was compared with an XM1 (developmental) tank, which obtained its combustion air through engine compartment grilles. The M60A1 tank was operated for 8.1 hours before the air cleaner restriction dropped to 25 in. (H_2O); whereas, the XM1 operated for only 63 minutes. In a second trial, after cleaning the filters with compressed air, the latter ran for 80 minutes. This comparison is cited to illustrate the difference in serviceability that can result from moving the combustion air intake to a location where dust surrounding the vehicle is minimal. Even had there been a leading vehicle, the dust concentration at the level of the M60A1 crew compartment intakes would have been lower than at the level of the XM1 intakes.

b. Weapons and Related Components

Most weapons tested required special emplacement on the gravel and hard-ground terrain found in the desert environment; however, the 105mm howitzer seated satisfactorily in all types of desert terrain.

One of the major problems of ground-based weapons has been muzzle blast (or breech blast in the case of rocket launchers and recoilless weapons), Figure II-24. This presents an almost insurmountable problem of security from observation and, particularly in the case of artillery and tank guns, makes observation of fire effect most difficult. Besides the problem of changes in ballistic characteristics arising from high ambient temperatures, elevated temperature of propellants and air density changes, which can be compensated for more or less satisfactorily, other effects such as exudation of explosive filler in ammunition are not

FIGURE II-21. AMPHIBIOUS VEHICLE OPERATION IN HIGH TEMPERATURE (>90°F) WATER

FIGURE II-22. DUST CLOUD TYPICAL OF WHEELED VEHICLE OPERATION – OPERATOR AND LOAD SUBJECTED TO HEAVY DUST CONCENTRATION

FIGURE II-23. TANK OPERATION ON DUST COURSE

FIGURE II-24. DUST CLOUD GENERATED BY FIRING TANK MAIN WEAPON. SHOCK WAVE PRODUCES DUST ALL AROUND THE VEHICLE AND BLAST WAVE RAISES SUFFICIENT DUST IN FRONT OF CANNON TO OBSCURE VISION OF TARGET.

so controllable and may even present major safety problems as temperatures of rounds lying on the ground or stowed in combat vehicles rise, Figures II-25, II-26, II-27.

Ancillary equipment of weapon systems is adversely affected by numerous aspects of desert operation. Vision problems arise because of muzzle blast, as previously mentioned, and heated air in the line of sight, but more serious problems in electronic control systems develop because of overheated components that break down or change their characteristics or are infiltrated by dust. Missile control amplifiers and stabilization control amplifiers on helicopters malfunction because of high temperatures, particularly when sitting on the ground, preventing proper preflight checkouts. Even though built-in cooling fans are provided, during normal flight operations of helicopters, the combined effects of high air temperatures (particularly in nap-of-the-earth operation); solar radiation heating, internally generated heat in electronic gear, and heat imposed by engine IR suppression components and power [illegible] conditions that cause failures or malfunction of laser designators, loss of stabilization of [illegible] overheating of computer elements, with attendant memory losses.

The T156E1 telescope, the M20 [illegible] the [illegible] range finder on the fire control system of the M48 Tank did not maintain [illegible] cross-country test. Such deficiencies are chargeable more to the rugged terrain of the desert than to excessive temperatures. The [illegible] of a vehicle-mounted machine gun broke during cross-country operation, Figure II-28.

In testing a hand-held laser range finder [illegible] dust cloud [illegible] a moving vehicle between the range finder and target [illegible] that only the range to the dust cloud was obtained. It was also observed that heat waves [illegible] prevented accurate ranging beyond 3000 m because of heat [illegible] and apparent movement of targets in the optical elements.

In a light-weight launcher for the [illegible] rocket system, after [illegible] cross-country course tests, binding of the rockets in the launcher tube caused partial hang-fires [illegible] a potentially hazardous situation.[34] A similar situation [illegible] Figure II-29 [illegible]

In a storage test of the M43E1 [illegible] heat caused darkening of the meter face, making it very difficult to read, Figure II-30.

The variation of temperature [illegible] many semiarid surfaces produces a tendency for stable air conditions during the night, an important consideration in employment of chemical agents and a consideration in ballistics. High daytime temperatures and the consequent decrease of air density are important in ballistics and may also create a need for longer airfield runways.

c. *Aircraft*

Aircraft are particularly subject to adverse conditions of the desert because of their operational roles, Figures II-31 and II-32. Helicopter gunships operate in nap-of-the-earth mode for considerable portions of their flight time, Figure II-33. Transport and cargo helicopters frequently load and unload in hovering mode, as well as flying at low levels for concealment, Figure II-34. Dust and debris is stirred up by rotor downwash, and unless particular attention is paid to designing such aircraft [illegible] of turbine elements and rotor blades can result in failures of these components in flight or excessive maintenance downtime, Figure II-35. This is most particularly a problem in the operating environment of sandy, dusty, dry deserts.

FIGURE II 25. EXTRUSION OF EXPLOSIVE FILLER AROUND FUSE WELL AFTER OPEN STORAGE AT HIGH TEMPERATURES

FIGURE II-26. EXTRUSION OF EXPLOSIVE FILLER AROUND CLOSING PLUG AFTER OPEN STORAGE AT HIGH TEMPERATURES

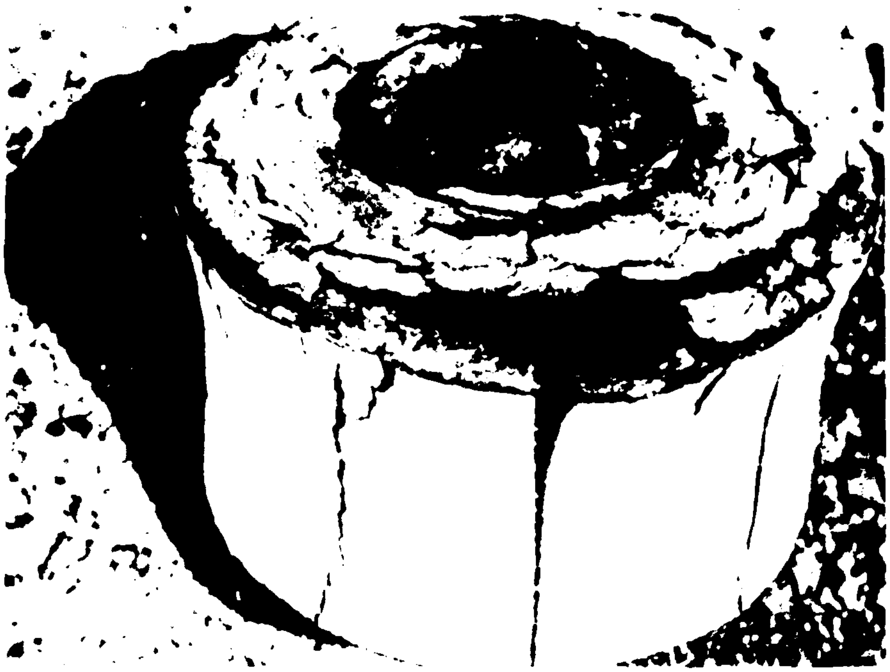


FIGURE II-27. SMOKE POT FUEL BLOCK – AFTER 5 YEARS STORAGE IN THE DESERT WOULD NO LONGER FIT IN THE SMOKE POT BECAUSE OF EXPANSION

FIGURE II-28. MACHINE GUN MOUNT LEGS FAILED

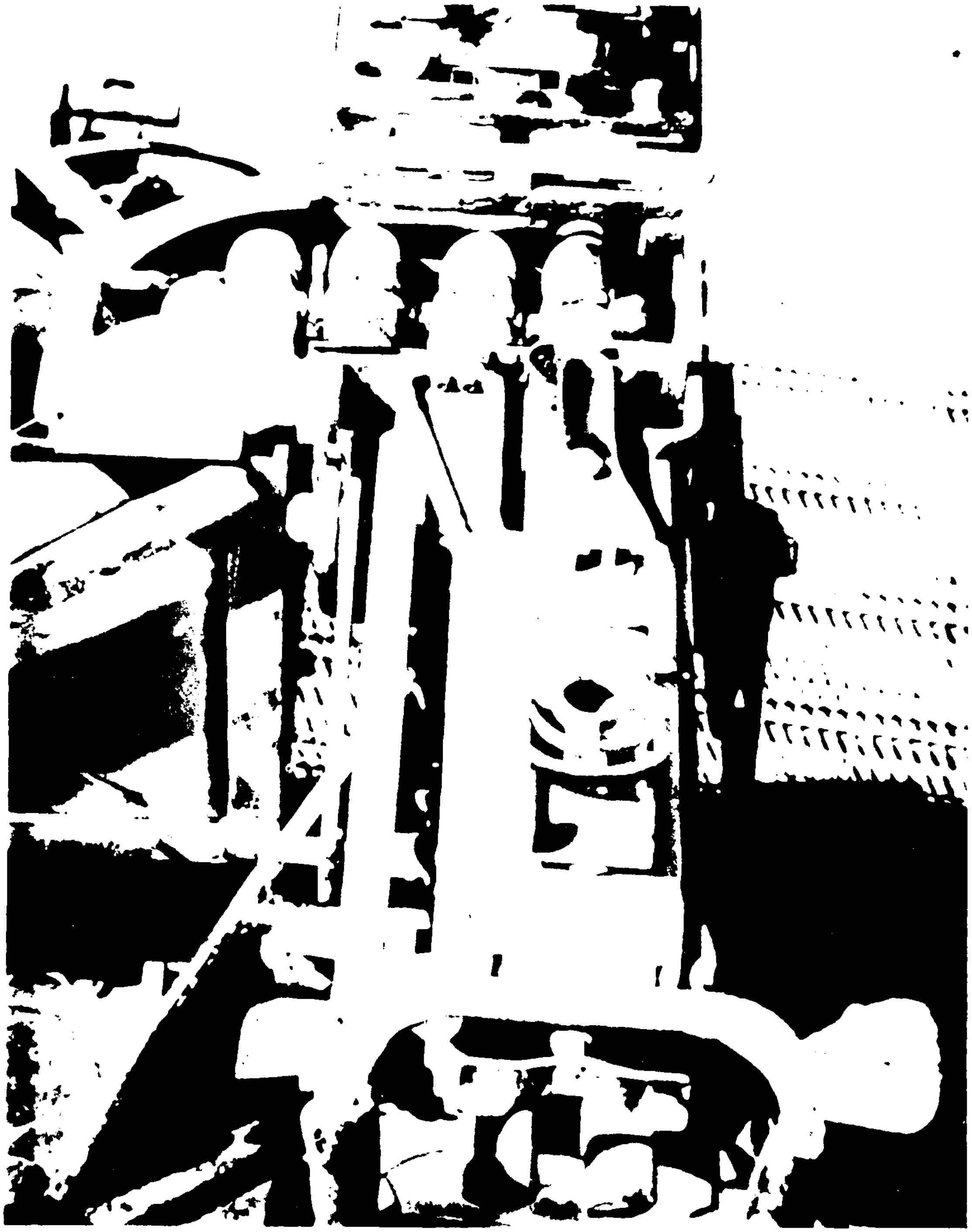


FIGURE II-29. 40 MM GRENADE LAUNCHER DUST CONTAMINATION

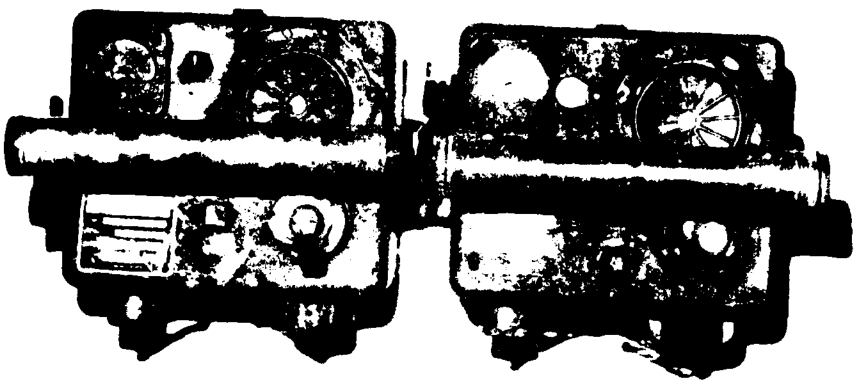


FIGURE II-30. DISCOLORATION OF METER FACE (LEFT) OF CHEMICAL AGENT DETECTOR KIT AFTER 12 WEEKS STORAGE COMPARED TO STANDARD UNIT (RIGHT)

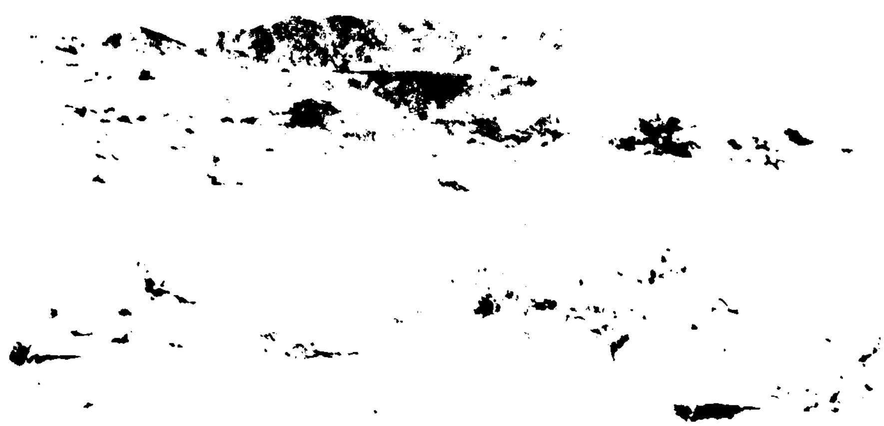


FIGURE II-31. DUST CLOUD DEVELOPED BY CARGO AIRCRAFT OPERATION FROM AN ASSAULT STRIP (REPRESENTATIVE OF FORWARD AIRFIELD IN A DESERT OPERATION)

FIGURE II-32. DUST CLOUD PRODUCED BY LOW ALTITUDE PARACHUTE EXTRACTION SYSTEM (LAPES) DELIVERY OF EQUIPMENT

FIGURE II-33. DUST STORM CREATED BY HELICOPTER ROTOR DOWNWASH

FIGURE II-34. DUST CLOUD PRODUCED BY CARGO HELICOPTER OPERATION

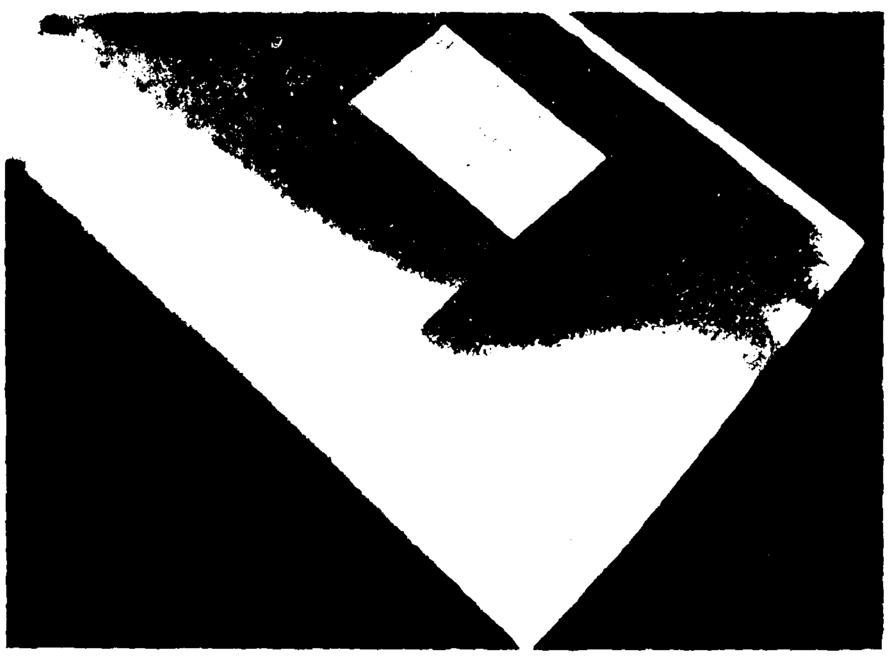


FIGURE II-35. HELICOPTER ROTOR TIP EROSION CAUSED BY DEBRIS IN THE AIR STIRRED UP DURING NAP-OF-THE-EARTH FLIGHT OPERATIONS

High temperatures on and near the ground may also seriously affect aircraft operation. The reduction in air density with elevated temperatures reduces the lift capability of the aircraft such that combat range, cargo capacity, or munitions loads may have to be decreased. The light structures of the aircraft heat rapidly from the effects of high ambient air temperature and solar radiation, and especially when the aircraft is on the ground, enclosed, poorly ventilated spaces can reach very high temperatures. As previously discussed in relation to weapons systems, if electronic or power elements are in these enclosed areas, failure or malfunctions can and do result.

d. *Construction, General and Support Equipment*

These classes of equipment include a very wide range of characteristics in such varieties as:

(1) Tractors, cranes, [illegible] equipment
(2) Water treatment systems
(3) POL storage and distribution equipment
(4) Air compressors, pumps, and welders
(5) Electric power generating equipment
(6) Air conditioning and refrigerating equipment, fans
(7) Food preparation equipment, steam boilers
(8) Uniforms, body armor
(9) Portable shelters, office vans
(10) Cameras, tape recorders, drafting equipment, typewriters

Much of this equipment is engine driven and thus subject to the same environmental problems as vehicular materiel, Figure II-36. In many instances, engine enclosures are utilized on this portable equipment to provide weather protection, reduce noise, or prevent IR radiation; however, great care must be exercised to ensure that such enclosures do not impose overheating problems at high ambient temperatures and that cooling air for the enclosed engine or radiator is adequately filtered to prevent clogging of cooling fins and that it is of adequate volume. It should be recognized that stationary equipment, even though portable, must be fan-cooled and may be adversely affected by ambient wind direction, as well as velocity, Figures II-37 and II-38.

In a dust test of a 10 kw gas turbine generator,[3] filtering of combustion air and exclusion of dust from cooling air were inadequate, and the following deficiencies were observed:

a. After 171.5 hours (161.5 hours of moderate dust, 10 hours of extreme dust), the turbine wheel broke (not positively established as dust related). Found upon disassembly:

1. Eroded turbine nozzle inlets
2. Eroded inlet sides of diffuser blade
3. Eroded insulation on wiring and circuit elements in generator

b. Compressor pressure discharge air line blocked, causing fuel control to operate improperly. Output reduced to 6.8 kw to keep exhaust gas temperature from exceeding maximum limit.

c. Improperly seated seal on air cleaner allowed dust to build up in bottom and tubes of air cleaner and other parts.

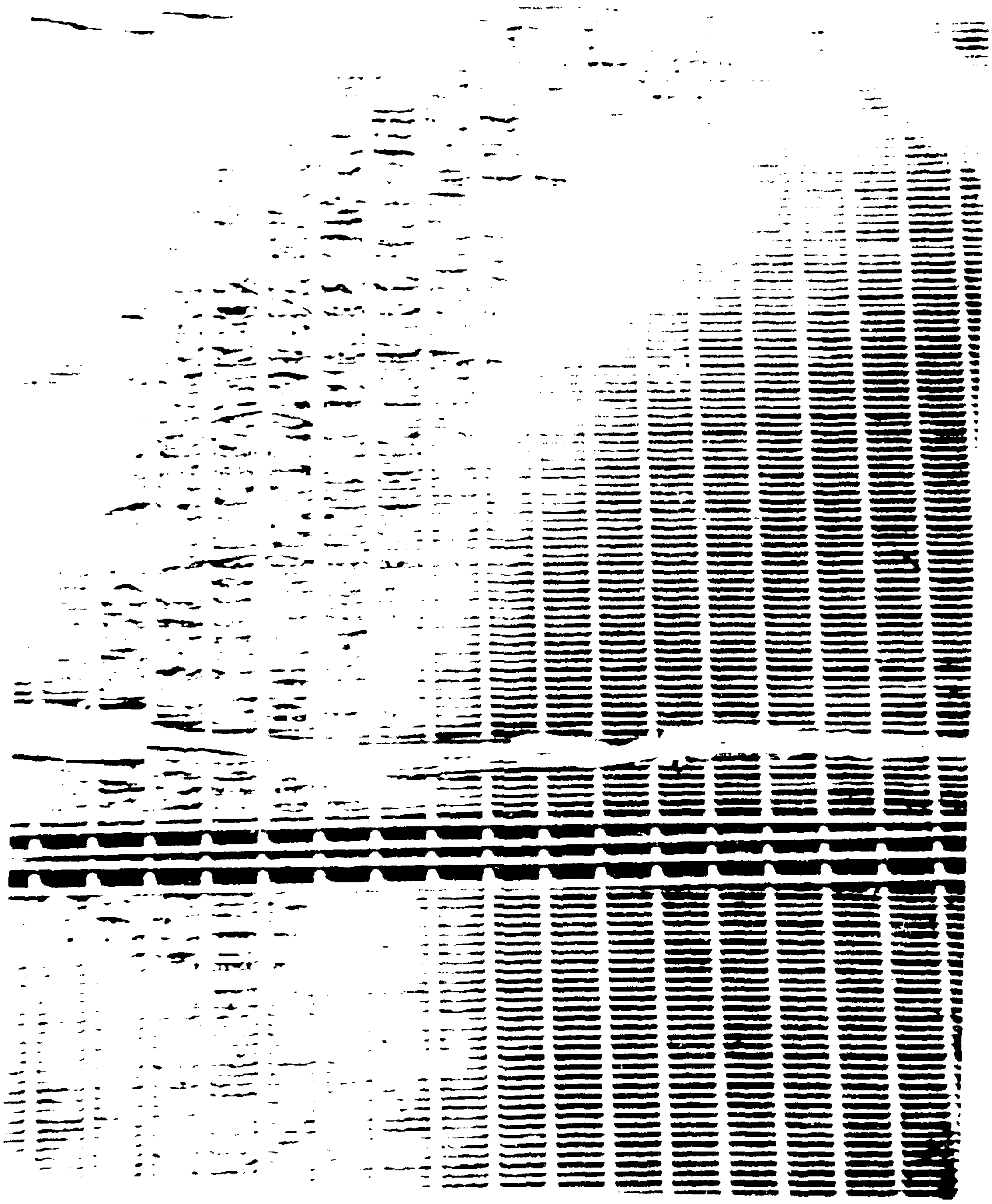


FIGURE II-36. SAND IMPACT AND DUST ACCUMULATION ON RADIATOR FINS OF CRAWLER TRACTOR AFTER 400 HOURS BULLDOZING OPERATION IN SANDY SOIL

FIGURE II-37. 10 KW GENERATOR SET PLACEMENT FOR EXTREME DUST TEST

FIGURE II-38. 10 KW GENERATOR SET DURING EXTREME DUST TEST

d. Because of oil leakage [illegible]

e. Inside of combustion chamber caked with dust.

f. Dust collected on terminal board and caused poor electrical connections to the fuel pumps.

g. Insulation around the combustion chamber became hard and brittle and broke into numerous pieces.

h. Battery cell caps were too close together to allow dust to be properly removed when servicing the battery.

i. Warning signs for "hot exhaust" became illegible.

In another test of equipment of this class,[36] a water tank trailer was operated for 3000 miles on roads and cross-country. Typical deficiencies observed were:

a. Cracking of the tank at the midsection showing bleeding and rusting of the outer surface and separation or sloughing away of the inner gel-coat lining.

b. Brake lining sloughed away (excessive wear, incorrect adjustment).

c. Cracks developed at right front mounting pad and at the right rear between tank and pad (excessive strain from cross-country operations).

Containers constructed of sheet materials, particularly certain plastics, deteriorate and fail under long-term exposure to high temperatures or solar radiation, or both, as experienced at YPG. Figure II-39 illustrates seam failure of a collapsable fuel storage tank. Figure II-40 illustrates plastic sand bag material deterioration and failure.

The wide variations in the characteristics of this class of materiel require that detailed study of each specific item precede any test initiation. Every effort should be made to determine all aspects of its employment, service, maintenance, and storage criteria, as well as procedures and results of any prior testing of this or related items. In particular, if this is a new item, reports of items having related or similar components should be reviewed. The principal concerns in all cases, however, are sand and dust accumulation on, and abrading of, moving surfaces, the effects of high temperatures on materials, and shocks and accelerations imposed by transport over rough desert terrain.

c. *General Operations*

During cross-country operations, dust clouds produced by tracked vehicles limit visibility to a considerable extent and betray positions. During tests of tracked, armored infantry vehicles, personnel compartment temperatures ranged from 15° to 18°F (8-10°C) above the prevailing ambient temperature, causing considerable crew discomfort. Opening of ventilation ports allows dust to enter the personnel compartment, causing further crew discomfort. The provision of respirators for vehicle occupants, as well as improved methods of air intake, is desirable but may be difficult. Continuous use of respirators at high temperatures is

FIGURE II-39. FABRIC COLLAPSIBLE FUEL STORAGE TANK – SEAM FAILURES

FIGURE II-40. PLASTIC SAND BAGS – AFTER ONE YEAR IN OPEN STORAGE [illegible] erting, as well as uncomfortable. High [illegible] operating personnel.

Heat and type of work dictate [illegible] a person in arid [illegible] man's daily water requirement while [illegible] when the temp[illegible] [illegible] C), 10 times that required [illegible] [illegible] rapidly when water intake [illegible] [illegible] the mean tempera[illegible]

Excessive heat causes a [illegible] difference in quality has been [illegible] 50 [illegible] temperatures in the [illegible] C) to over 100 F (38 [illegible] greatly increases man's need for w[illegible] [illegible] percent.

High temperature [illegible] food [illegible] because the deterioration is more rapid at [illegible] their nutritive [illegible] spoiled. As previously indicated, high te[illegible] [illegible] constituents [illegible]

III. U.S. ARMY YUMA PROVING GROUND

A. LOCATION

Yuma Proving Ground (YPG), the U.S. Army's principal desert test center, is situated in the extreme southwest corner of Arizona, near the City of Yuma. Although authorities differ slightly in identifying some of the western deserts and their respective boundaries, Yuma Proving Ground is generally considered as lying in the Sonoran desert,[38,40] one of the major North American deserts. Extensive areas in the western U.S. desert regions are sites of other U.S. Army, Navy, and Air Force activities because of either areal extent or environmental characteristics, or both. Figure III-1 illustrates the location of YPG with respect to some of these areas and with respect to some major western population centers and physiographic features. Among those indicated are:

- U.S. Army Electronic Proving Ground, Fort Huachuca, about 60 air miles (100 km) southwest of Tucson, Arizona, and 250 miles (400 km) east of YPG. It is also the U.S. Army Communication Command Headquarters and the location of the Army Intelligence Center and Intelligence School. Unique characteristics qualifying it for its primary mission are its clear electromagnetic environment and freedom from aircraft congestion.

- Dugway Proving Ground, some 500 miles (800 km) north near Ogden and Salt Lake City, Utah, is now combined with Deseret Test Center and has as its mission test and development of chemical warfare and biological defense systems (CW/BD). A portion of the Proving Ground extends into the southern reaches of the Great Salt Lake Desert.

- China Lake Naval Weapons Center (NWC) and Mojave "B" Randsburg Wash Test Ranges are about 275 miles (440 km) northwest of YPG and are the test and development centers for air-launched weapons and smaller caliber gun-fired ordnance for the U.S. Navy.

- Edwards Air Force Base, an advanced concepts development center, is about 75 miles (120 km) south of NWC.

- Nellis Air Force Base and Nuclear Testing Site occupies a large area in Nevada northwest of Las Vegas and about 450 miles (725 km) north of YPG.

- Luke-Williams Air Force Bombing and Gunnery Range lies directly south of YPG, extending eastward.

- White Sands Missile Range, a National Missile Range, serving the U.S. Armed Forces, NASA, and private industry, surrounds the White Sands National Monument about 450 miles (725 km) east in New Mexico, just north of El Paso, Texas.

- Death Valley, about 300 miles (480 km) northwesterly from YPG, is a responsibility of the Bureau of Land Management of the U.S. Department of the Interior and, although not dedicated to desert testing, is used in YPG projects under special arrangements with the National Park Service when unique environmental qualifications of that area are needed.

- San Diego is approximately 150 air miles (240 km) west on the Pacific Coast.

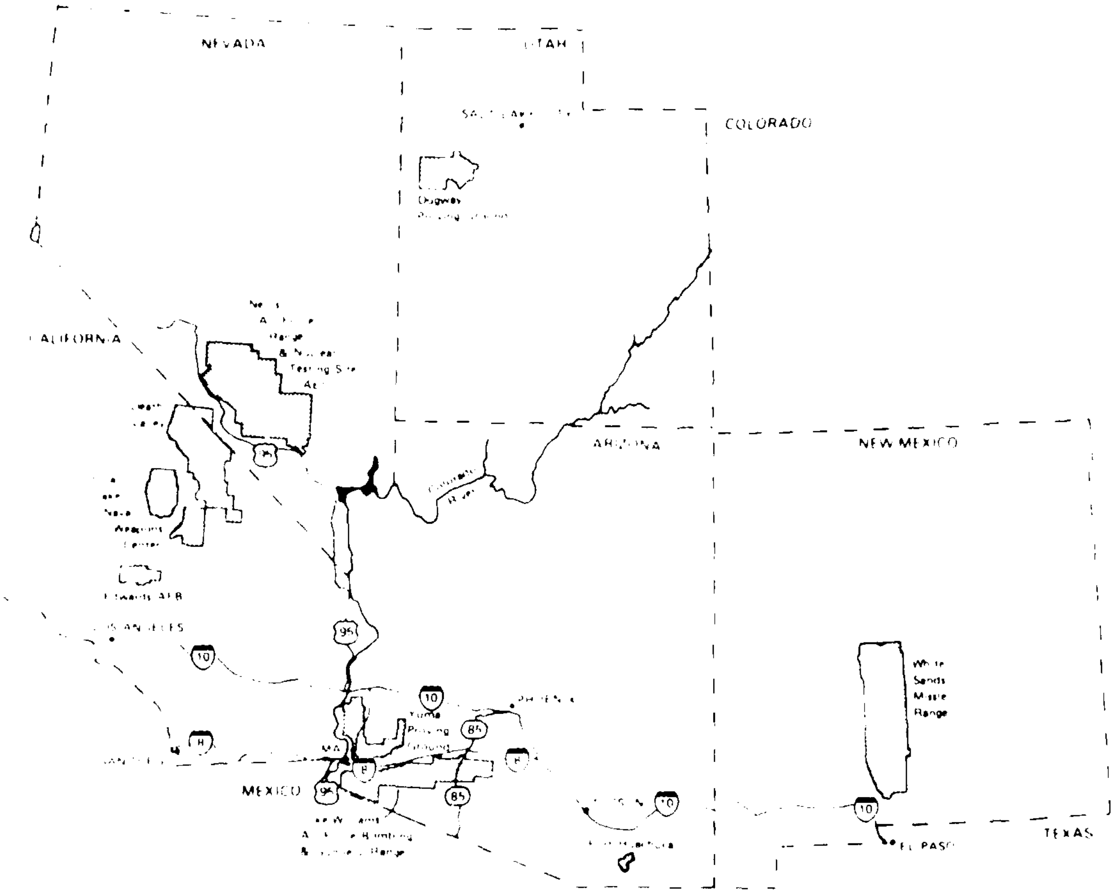


FIGURE III 1. LOCATION OF YUMA PROVING GROUND WITH RESPECT TO OTHER DOD ACTIVITIES IN THE WESTERN UNITED STATES

- Los Angeles [illegible]

- The Phoenix Tempe Me[illegible]

Arid and semiarid regions of western No[illegible] ment for these various activities, extend from Sonora and C[illegible] through the southwestern and western [illegible] extent. Wahluke weather station in southern W[illegible] reports mean annual precipitation of [illegible] (48 C)[illegible], as compared to Yuma [illegible] miles (1035 km) south [illegible] temperature of 124 [illegible] but across the Gulf of C[illegible] weather station report[illegible] 2.5 in. (6.4 cm)[illegible] to the Pacific Ocean with [illegible] desert areas oriented [illegible] state

B PHYSIOGRAPHY

Physiographic [illegible] bian Plateau Province [illegible] ceding paragraph [illegible] essentially parallel ridges [illegible] of the Great Basin [illegible] west in Nevada, [illegible] Black Rock [illegible] tion. Northwestern Utah [illegible] Nevada are Ralston [illegible] thoritative sources [illegible] boundaries [illegible] considered sufficient [illegible] tures as applicable. Politically [illegible] and Man*agement* Act of 1976 (the BLM [illegible] California desert to the Bureau of Land [illegible] important as a major [illegible] test and driest climate in North America [illegible] nineties, and precipitation is generally [illegible] much of northwestern Mexico and Baja California [illegible] Desert area in Mexico include the [illegible] Desert of northern Sonora [illegible] which lies along the Pacific Coast of Baja California, and the Gulf Coast [illegible] of Baja California, Sonora, and Sinaloa along the coast [illegible] Sonoran Desert includes or adjoins, according to the respective authorities, the [illegible] Mojave [illegible] Desert. In defining the Sonoran Desert, Fenneman [illegible] Mojave [illegible] area in the Province is that occupied by Death Valley National Monument [illegible] Nevada-California line. Much of Death Valley [illegible] Bad water being the lowest in the United States [illegible]

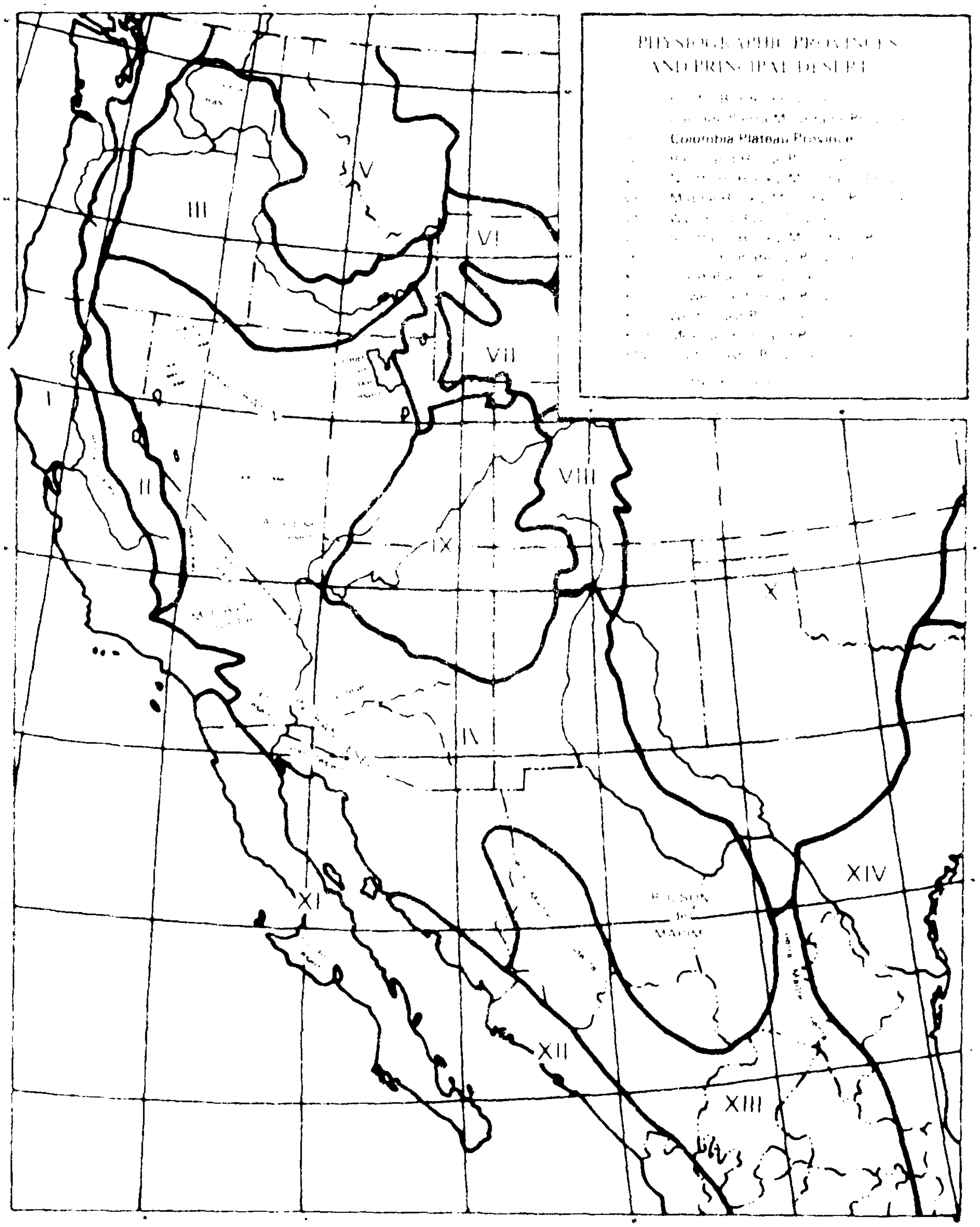


FIGURE III 2 PHYSIOGRAPHIC PROVINCES OF WESTERN UNITED STATES [illegible] and west of Death Valley, average about [illegible] elevation. Although Mt. Whitney [illegible] the Province and only 78 miles ([illegible] km) west of Death Valley, is the highest peak in the conterminous United States, 14,497 feet (4419 m).[41] The Salton Trough [illegible] Brawley and Indio, encompass[illegible] and Imperial Valleys and the Salton Sea [illegible] (83.4 m) below sea level.[4,41] The elevation of the surface of the Salton [illegible] feet below sea level [illegible][44] depending upon the [illegible]. The Colorado Desert [illegible] somewhat the same area as the Salton Trough [illegible] Dunes) and the Chocolate Mountains [illegible] Yuma and U.S. Highway [illegible] Colorado River Delta.

Another major desert [illegible] huan Desert. It lies mainly in Mexico [illegible] southern Arizona and New Mexico [illegible] area.[4]

The City of Yuma [illegible] southwestern corner of Arizona [illegible] (30 km), San Luis, Arizona, and [illegible] Mexico border [illegible] 8 passes through Yuma [illegible] km) to the north. Interstate [illegible] Proving Ground lies between the two [illegible] almost 55 miles (88 km) [illegible] Arizona (32° 40' to 33° [illegible] (32 km) from the City of Yuma [illegible]

Geomorphically [illegible] the southwestern part of [illegible] tion of that province [illegible] Plateau [illegible] plateau bordered on the west by [illegible] Mogollon Rim [illegible] elevation over much of the Plateau [illegible] mountains. Between the Plateau [illegible] the mountains forming the western and [illegible] faulted Plateau and the [illegible] faulted [illegible] in the [illegible] westerly direction, elevation of the [illegible] Al[illegible] though individual mountain ranges in the [illegible] area lies above 3,000 ft (900 m), and [illegible] 2,000 ft [illegible] between [illegible] level and 1,000 ft (300 m).[33] Yuma Proving Ground [illegible] confluence of the Colorado and Gila Rivers. Characteristic [illegible] drain internally. In the area of the Province [illegible] however, the basins [illegible] Erosion and removal of weathering [illegible]

C   YUMA PROVING GROUND AND SURROUNDING AREAS

As can be seen in [illegible] Yuma [illegible] of Yuma, Arizona [illegible] Colorado River and north [illegible] Southern Pacific Railroad

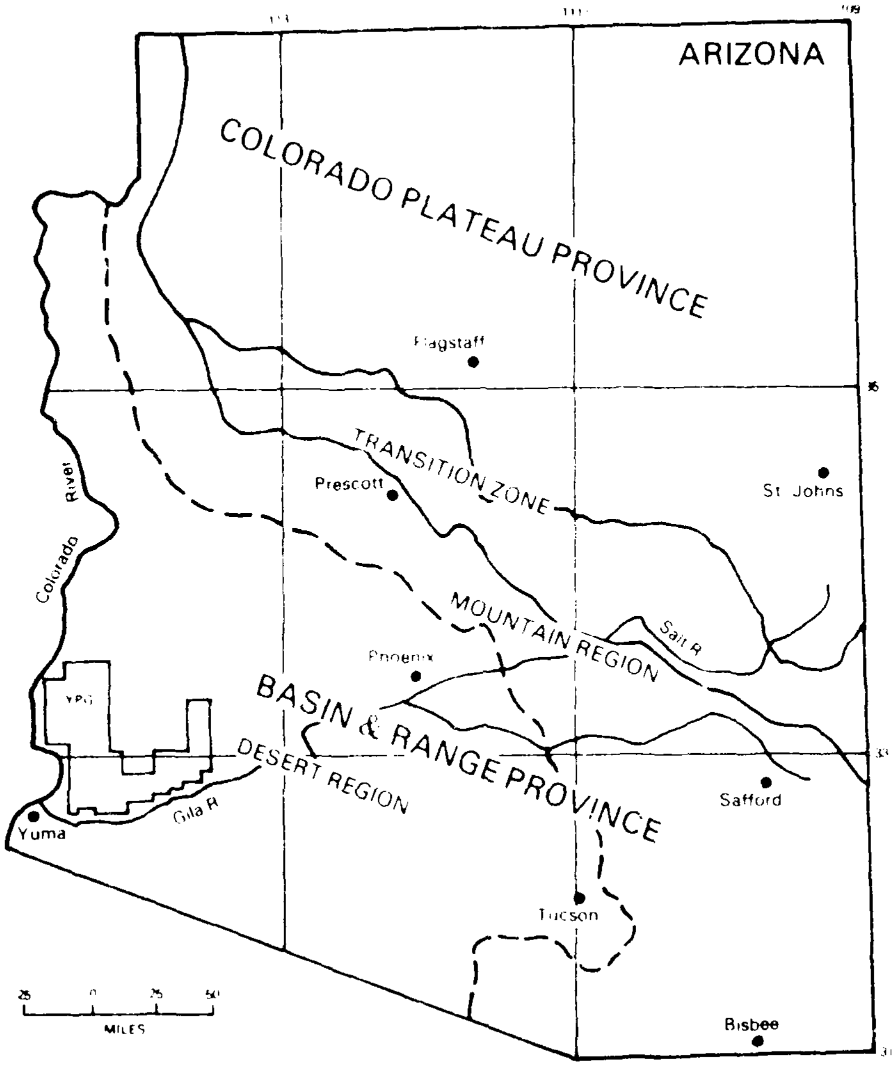
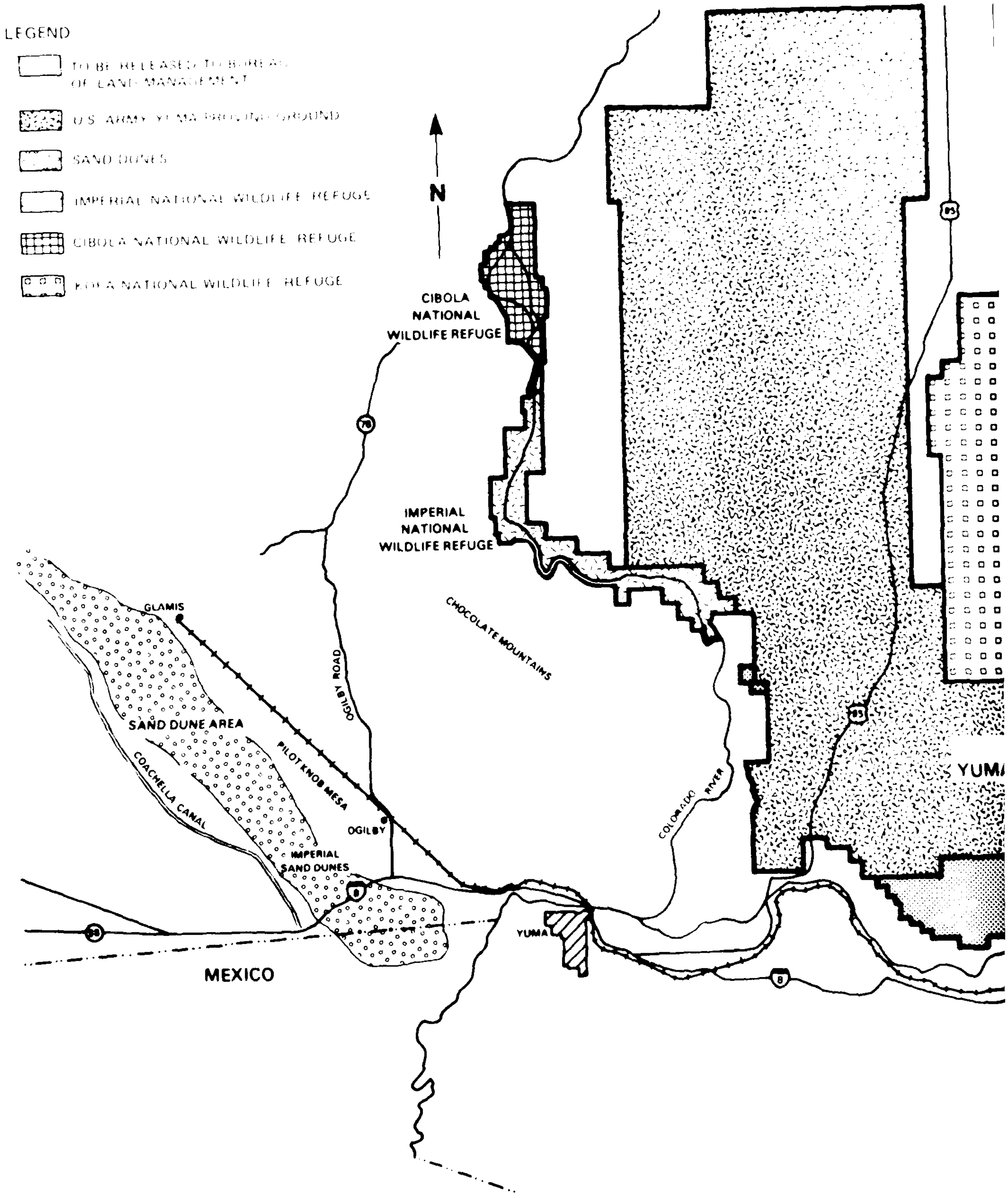


FIGURE III 3 PHYSIOGRAPHIC PROVINCES IN ARIZONA

Across the Colorado River, west about 40 miles (64 km), is a sand dune area available for vehicle mobility and durability tests in that environment, accessible by highway, or by rail if necessary, via the City of Yuma, Arizona, and Ogilby, California. In the immediate vicinity of the Proving Ground are the KOFA (King of Arizona) National Wildlife Refuge, lying almost in the center of the reservation, and Imperial and Cibola National Wildlife Refuges, stretching about 45 miles (72 km) in California and Arizona along the Colorado River just west of the Proving Ground. The refuges are not routinely used in Proving Ground test activities, although limited areas of the Imperial Refuge are utilized for fording tests, and the KOFA refuge may be used for scientific research.

The area constituting Yuma Proving Ground is one of the largest uninhabited areas of the United States, consisting of over 870,000 acres (350,000 ha).[36] In the form of a huge "U" open to the north, its overall extent is almost 53 miles (85 km) in the north-south direction and 6 miles (103 km) east-west. The western north-south arm varies from 12 to 19 miles (19 to 30 km) in width, the eastern arm is 18 miles (29 km) in the


LEGEND
SAND DUNES
IMPERIAL NATIONAL WILDLIFE REFUGE
CIBOLA NATIONAL WILDLIFE REFUGE
NATIONAL WILDLIFE REFUGE
N
CIBOLA
NATIONAL
WILDLIFE REFUGE
IMPERIAL
NATIONAL
WILDLIFE REFUGE
CHOCOLATE MOUNTAINS
OGILBY ROAD
GLAMIS
SAND DUNE AREA
COACHELLA CANAL
PILOT KNOB MESA
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SAND DUNES
COLORADO RIVER
YUMA
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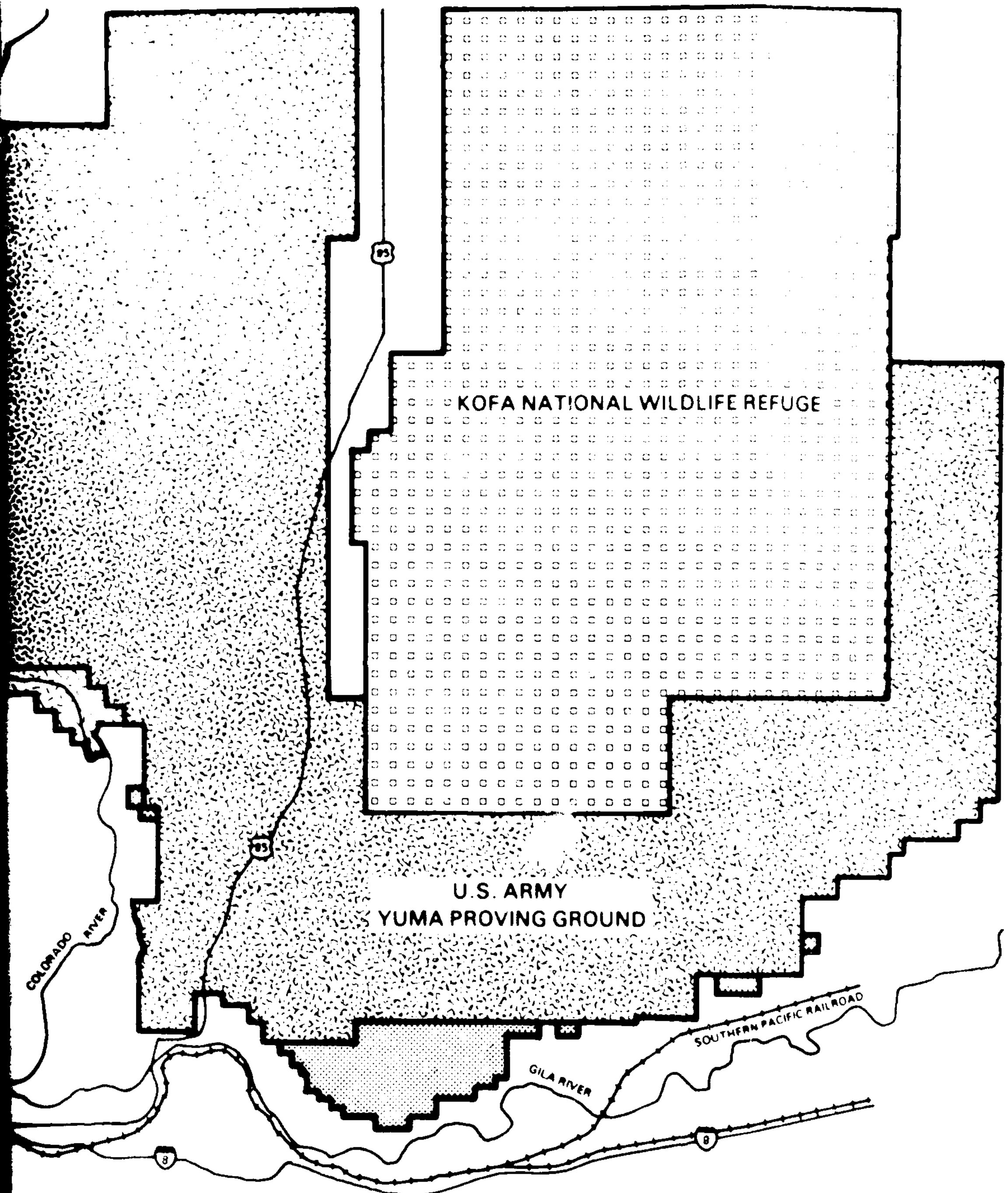

FIGURE III-4. YUMA PROVING GROUND AND IMMEDIATE VICINITY north-south direction and [illegible] Proving Ground [illegible] varies in width and length because of the [illegible] Regulations [illegible] A though 35 to 43 miles (56 to 69 km) [illegible] miles (23 to 29 km) in an east-west direction [illegible] still under Army control [illegible] 35,000 acres [illegible] principally along the southern [illegible] in adequate [illegible]

KOFA National Wildlife Refuge [illegible] KOFA Game Range [illegible] comprised of about 1000 square miles (2600 km²) [illegible] 24 [illegible] west direction and [illegible] about half [illegible] with YPG boundaries. Between [illegible] north-south [illegible] a strip administered by BLM [illegible] its point of exit from YPG [illegible] Quartzsite [illegible] Mountains, the northwest [illegible] KOFA [illegible] the refuge. Elevations range from [illegible] feet [illegible] YPG to peaks, some of which reach [illegible] 4877 ft (1487 m), followed by Signal Peak [illegible] KOFA Butte, 3250 ft (991 m) [illegible] extends to the Refuge [illegible] and Wildlife Service [illegible] which permits certain forms [illegible] activity unless specifically [illegible] designated existing roads. Because [illegible] 4-wheel drive [illegible]

Imperial and Cibola Wildlife Refuges [illegible] the U.S. Fish and Wildlife Service [illegible] YPG [illegible] corner of Imperial Refuge [illegible] following the meander [illegible] the Proving Ground [illegible] and birds. Where [illegible] bombing on a controlled basis [illegible] River from eastern [illegible] Under arrangements with [illegible] vehicles may be tested [illegible]

Three additional [illegible] material test [illegible] guarded for [illegible] Under agreement with [illegible] Lake Wildlife Refuge [illegible] Martinez [illegible] Dam. A [illegible]

The Land Bureau [illegible] part of the Federal Land Policy and Management Act of 1976 (BLM) [illegible] Conservation area established by the U.S. Congress [illegible] Organic Act [illegible] The open land area [illegible] fornia Mexico line [illegible] by the Southern Pacific Railroad from [illegible] of the Bureau of Land Management [illegible] operation [illegible]

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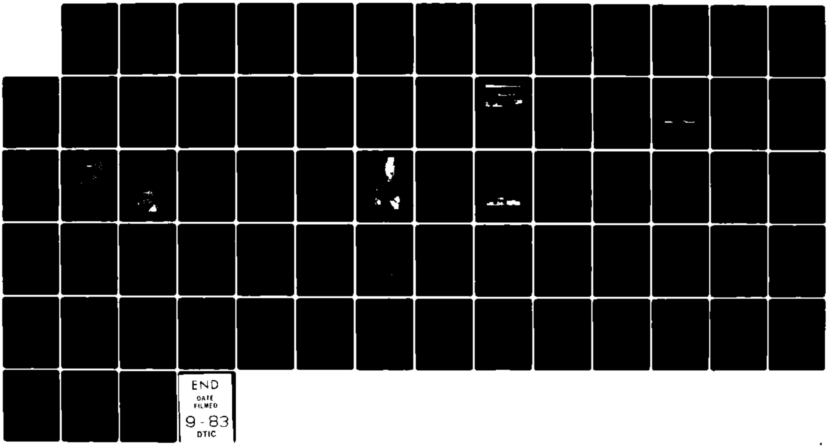
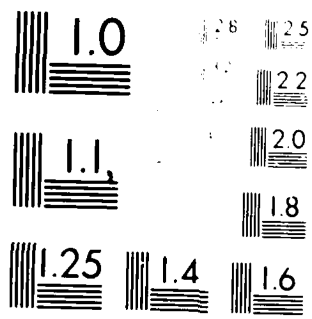



1.0
2.5
2.2
1.1
2.0
1.8
1.25
1.4
1.6

or the Imperial Dunes, or for test purposes at YPG simply the sand dunes or sand hills. They occur in a belt about 40 miles long (60 km) and 3 to 6 miles (5 10 km) wide, roughly paralleling the Southern Pacific Railway,[44] and they include extensive areas of sandy plains, sand hills, and a variety of dune formations, with natural sand slopes up to 60 percent for mobility tests.[32] In the central and southern part of the dune area, some slip faces are 200 to 300 feet (60 90 m) high and overlook large, flat-floored, sand-free depressions interpreted as exposed parts of the desert floor over which a succession of barchans is advancing.[55] A 7-mile (11 km) marked course was used by YPG for mobility testing. Although this natural dune area has been under BLM administration since 1976, the Proving Ground can use this area by coordinating with that agency.

Climatic characteristics and terrain features of Yuma Proving Ground and comparisons of them with similar measures of other world deserts are contained in many publications, and some are suggested as references for more detailed information.[22,37,38,45,48,51,55,56,67,74,76] As a hot desert test center for Army materiel, the summer environment of YPG is of principal interest, although summer tests have extended into fall for test completion because of a late start or interruption during a test. Too, if desert terrain and topography are of overriding importance to test objectives, and climatic and terrain factors are not synergistic, tests outside the usual desert summer climatic conditions may satisfy test requirements. Certainly, military operations in extremely hot, dry desert regions, such as the Libyan Desert, have encountered environmental conditions not usually thought of as characteristic of that environment.

It is worthwhile, therefore, to consider the total annual Yuma climate, characterized by long, hot summers, wide diurnal temperature variation, intense solar radiation, low relative humidity, high visibility, and scant annual precipitation.[37] Maximum, minimum, and average values of climatic factors at Yuma are contained in Table II-2. It is useful, however, for the materiel designer, test planner, and project officer to be aware of diurnal, seasonal, and annual variations and in some cases the location of the meteorological station reporting data of interest. It may also be pertinent to know the frequency of occurrence and persistence of environmental phenomena.

The Yuma Weather Station in downtown Yuma, moved to Yuma airport in 1951, was the sole source of meteorological data for the vicinity prior to that time. With reactivation of Yuma Test Station and establishment on the reservation of a meteorological station by the U.S. Army Signal Corps, observations directly on the Proving Ground became available. Initially, the Signal Corps weather station was located in the main post area, but in 1954 it was moved to the present Mobility Complex. Several studies have been made of the influence of station location on recorded meteorological data.[38,66,71,72] Some are concerned with correlations between data developed by the U.S. Weather Bureau Station at Yuma and that obtained by the meteorological station on the Proving Ground.[66] Others are concerned with correlation between observations at various locations on and in the vicinity of the Proving Ground.[71,72] Records of the Yuma Weather Station date from the early 1870's and, because of the length of record, provide reliable data bases for determination of long-term maximums, minimums, means, durations, etc. Available studies do not differentiate between observations at the two Yuma weather station locations, but apparently, consistency and correlations are satisfactory. Research Study Report PER-16 compared meteorological records at Yuma Test Station and Yuma Weather Bureau, and no significant differences were found in temperature, precipitation, winds, relative humidity, or cloudiness.[66] For the 5 years covered by that study, mean monthly temperatures at the two stations differed by only 2°F (1.1°C) maximum; Yuma Test Station averaged 0.55 inches (1.4 cm) more precipitation a year than the Yuma Weather Bureau; winds were 2 to 3 mph (35 km) higher at the Weather Bureau than at the Test Station; differences in mean relative humidity were slight. The Test Station experienced slightly fewer clear and partly cloudy days than the Weather Station. The study concluded that differences in climatic observations at the two stations did not appear great enough to necessitate consideration by test planners and that conditions within a testing area might differ more than those observed between the two meteorological stations.[66] A series of climatic analogs for YPG with other desert areas of the world[37,56,65] accordingly used the records of the Yuma Weather Bureau. Meteorological observations at disbursed sites in and around the southwestern segment of the reservation indicate quite close uiformity for maximum summer temperatures at the standard height above ground surface. Ambient temperature records for the main weather station on the Proving Ground can, accordingly, be used for general test planning purposes. For tests in which significant factors are air temperatures at other than standard heights above ground surface, at or below ground surface, wind, dew point, relative humidity, insolation, etc., the particular site to be used should be investigated in detail beforehand and provisio is made to measure those factors during the test period. Some of the climatic factors of interest to the test planner and characteristics of those factors at Yuma Proving Ground are outlined in the following sections.

D. YUMA ENVIRONMENT

1. Climate

a. *Temperatures*

(1) Ambient

An absolute maximum of 123°F (50.6°C) was recorded at Yuma in September 1950, measured at the original weather station location in downtown Yuma. More useful than this statistic, however, are other temperature characteristics of the area, such as the calendar periods of occurrence of specific temperature levels, frequency of occurrence within those periods, hourly duration, etc. Some of these phenomena are indicated in Figure III-5, which is based on temperature records dating from about 1910. The curve for mean maximum shows temperatures of 100°F (38°C) or higher for each month from June through September and 95°F (35°C) or higher for a slightly longer period beginning in May. The hottest month of the year is July, for which a mean maximum of approximately 106°F (41°C) is indicated. The curves of mean, mean minimum, and absolute minimum are useful in the planning of tests in cooler weather or for those conducted over extended periods, such as static exposure. Figure III-6 consists of two curves illustrating the frequency of occurrence of daily maximum and minimum temperatures for the month of July. It shows, as an example, that temperatures of 100°F (38°C) or higher can be expected on 29.9 days of that month. Data for these curves is from an analysis of 25 years of weather records, which developed similar curves for the occurrence of extreme temperatures for each month of the year. Those curves are available in the same document.[38] Somewhat similar data in possibly a more convenient form is presented in Figure III-7, covering the 7 hotter months of the year for 5 years and showing occurrence of temperatures of 95°F (35°C), 100°F (38°C), and 105°F (41°C) during each month and diurnal time and number of days of occurrence. Confirming the previous illustration, this chart shows 100°F (38°C) or higher temperatures occurring on 30 days during July (in a later time frame than the previous example). In showing time of occurrence of 105°F (41°C) or higher from 1345 to 1745 hours in June and July, it is also in general agreement with an illustration, Figure III-8, from still another study by Llewelyn.[71] This figure is a simplified presentation of the occurrence of maximum temperatures for 2 days only, one in June and one in July, out of a total of 97 days considered in the entire analysis. From the curve of air temperatures, it can be seen that maximum levels (in these cases about 110°F (43°C) or higher) occur between about 1400 and 1800 hours. The set of curves shown, including dew point and humidity for each maximum temperature point, was developed from an investigation of climatological conditions favoring occurrence of high temperature at the Proving Ground and provides important information concerning the high temperature environment, of use to designers and test planners. Its consideration of

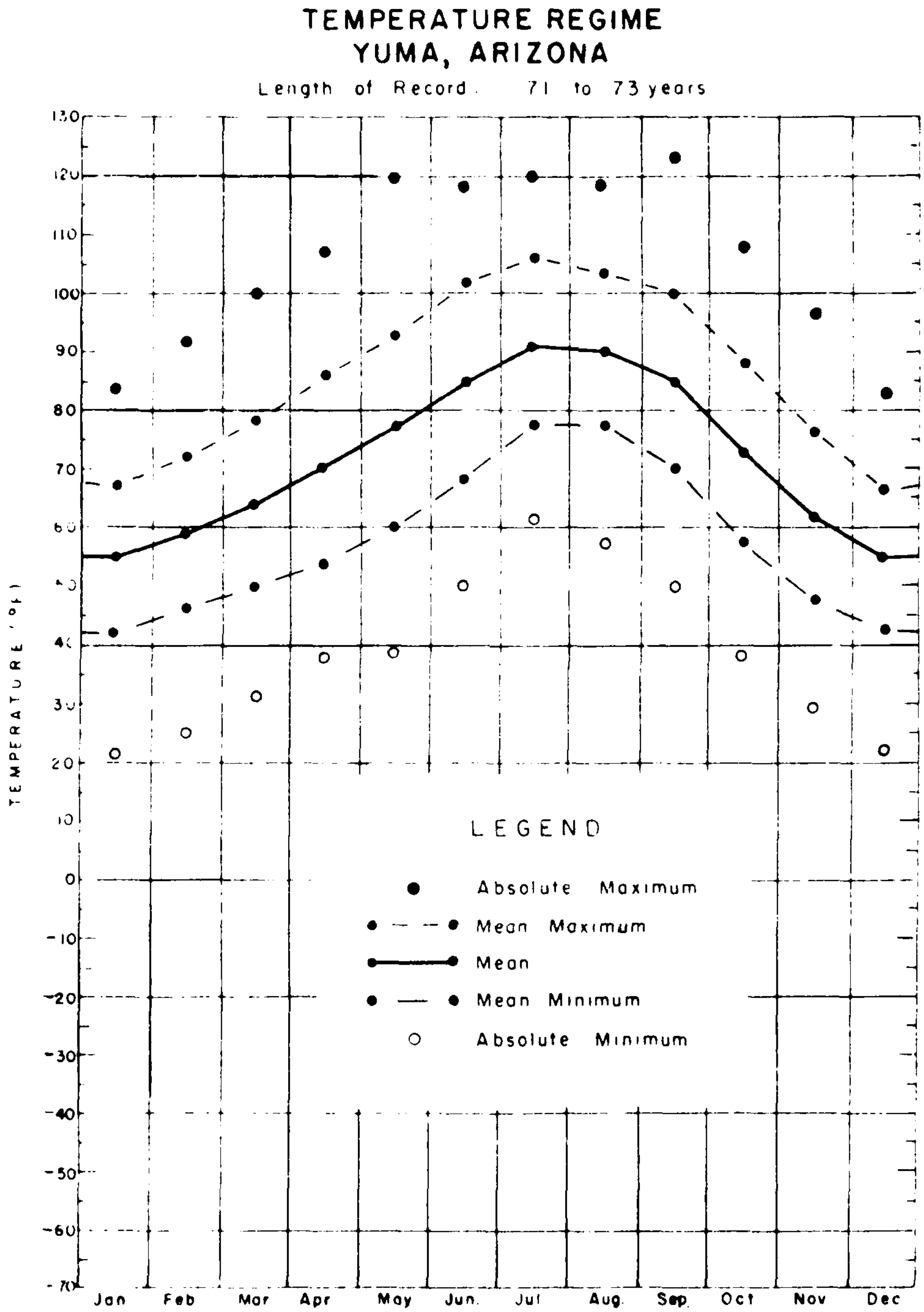
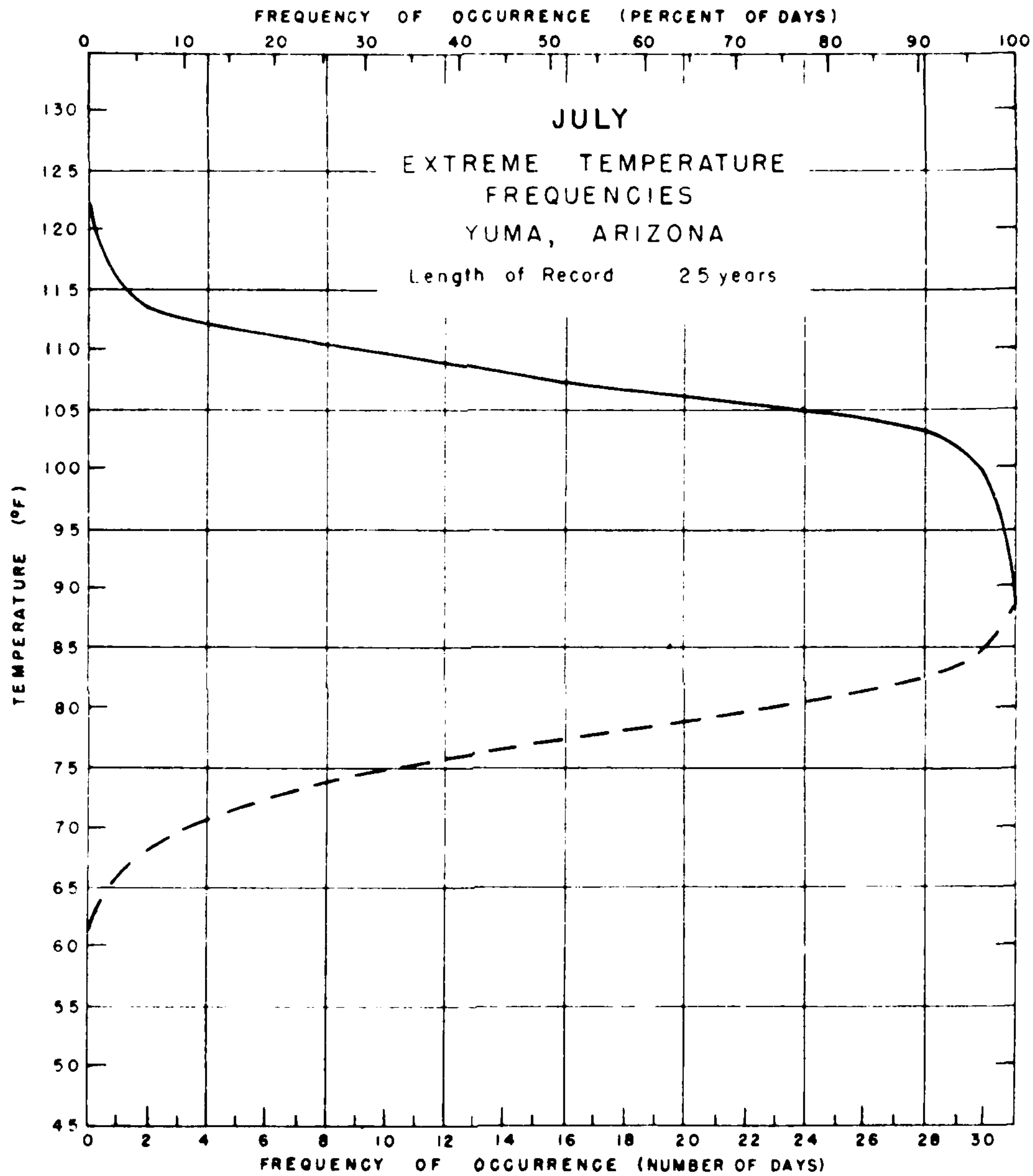


FIGURE III-5. TEMPERATURE REGIME, YUMA, ARIZONA



—— Number of days (or percent of days) the daily maximum temperature may be expected to equal or be greater than a particular temperature.

— — Number of days (or percent of days) the daily minimum temperature may be expected to equal or be less than a particular temperature.

Example: A maximum temperature of 100°F or greater may be expected 29.9 days during July.

FIGURE III-6. JULY EXTREME TEMPERATURES, YUMA, ARIZONA

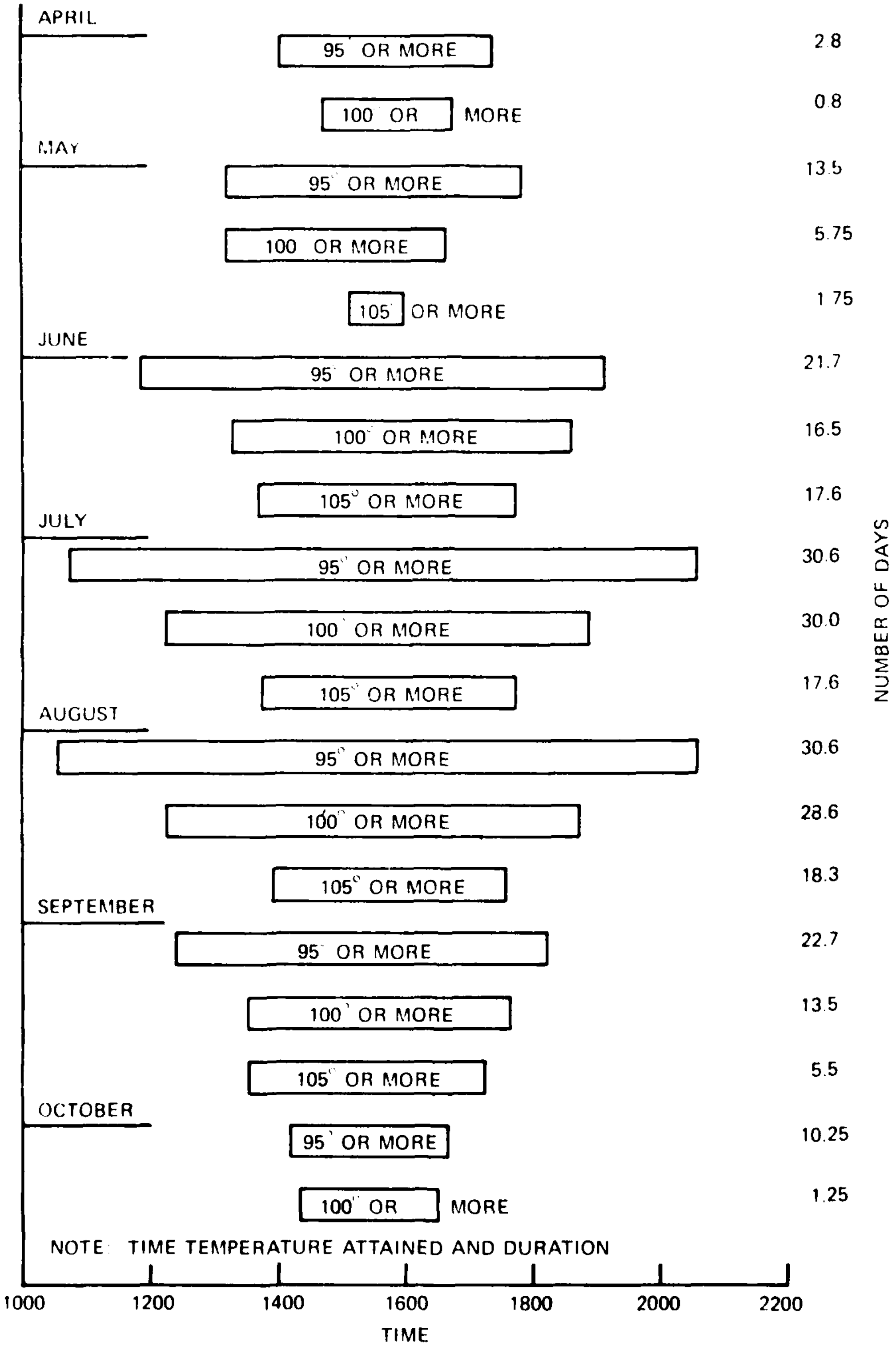


FIGURE III-7. TEMPERATURE SUMMARY – APRIL 1964 TO OCTOBER 1968

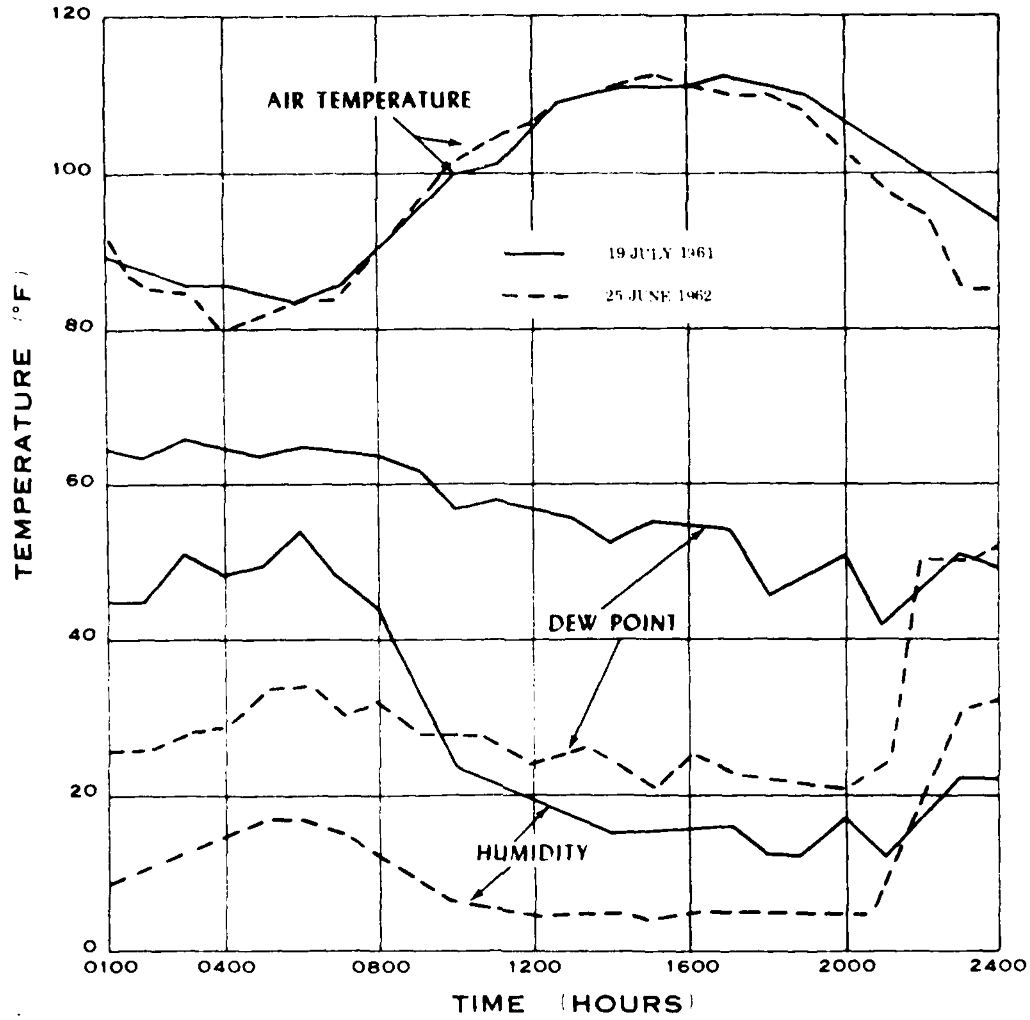


FIGURE III-8. AIR TEMPERATURE, DEW POINT, AND RELATIVE HUMIDITY REGIMES 19 JULY 1961 AND 25 JUNE 1962

the occurrence of high temperatures, applicable not only to Yuma but also to other desert areas as a result of influences of environmental factors, shows relationships between each, plus supplemental information consistent with the purposes of this discussion. Basic data used in the study is identified only as "meteorological data taken at the Army desert test station near Yuma, Arizona," and this study is limited to presenting the analysis of data observed during days with "afternoon temperatures . . . of 105°F (41°C) or higher. Ninety-seven such days occurring during the warmer months of *1961, 1962 and 1963 are used in this study.*" Afternoon temperatures are defined as the average of the hourly shelter (weather station shelter) maximum temperatures for a 5-hour span. The 5-hour span encompasses, essentially, all of the comparatively flat top of the diurnal temperature curve which occurs, with few exceptions, within the hours 1400 to 1800. The hourly duration of ambient temperatures is indicated somewhat differently in Figure III-9, based on temperatures observed in July and August 1956,[71] a summer microclimate study. In this figure, mean hourly temperatures are shown for various heights above and below ground surface, as well as at the 200 cm (79 in.) level. At that level, mean temperatures of 100°F (38°C) and higher occur from about 1300 to 1800 hours. The data upon

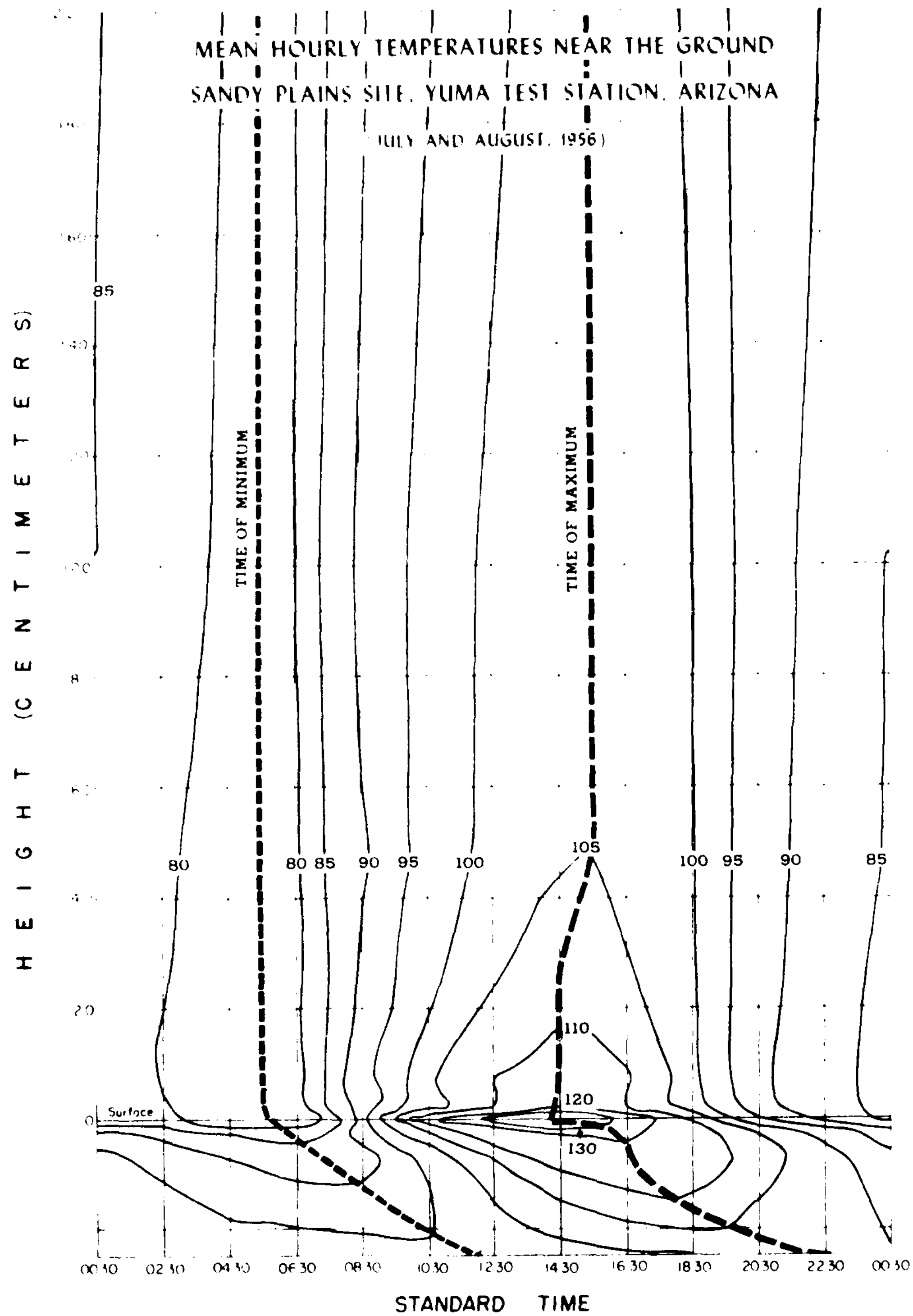


FIGURE III-9. MEAN HOURLY TEMPERATURES NEAR THE GROUND, SANDY PLAINS SITE, YUMA TEST STATION, ARIZONA which the isotherms are based were recorded at "Sandy Plains", one of three sites specifically instrumented for summer microclimate study. The site is generally representative of those most used in many tests; the data is, accordingly, applicable with some confidence to other similar test sites and areas, although its use should be tempered by awareness that the data were obtained during the hottest months of the year at Yuma. In Figure III-10, temperature profiles at three observation sites, including "Sandy Plains", are plotted.[72] Temperatures at the 200 cm (79 in.) level vary by a maximum of only 2 degrees (1.1°C) among the three sites, suggesting confirmation of other findings of uniformity of ambient temperatures at various test sites. They were observed under selected conditions of maximum ground surface temperature, however, and do not indicate possible influences of such factors as site elevation and wind speed and direction at each site.

Temperatures below 200 cm (79 in.)—Figure III-9, referenced in the preceding paragraph, presents composite isotherms for the months of July and August for the "Sandy Plains" site. Temperatures were measured at 2.5, 7.5, 25, 50, 100, and 200 cm (1, 3, 10, 20, 39, 79 in.) above ground surface. As might be expected, temperatures from just above the surface to the 200 cm (79 in.) level are relatively uniform, about 80°F (27°C), during early morning hours of darkness, but beginning at about sunrise, temperatures above the 7.5 cm (3 in.) level begin to lag progressively behind those at and just above the surface, reaching a maximum at about 1530 hours. At that time, the temperature is 130°F (54°C) just above the ground surface, 106°F (41°C) at 16 in. (40 cm), and 100°F (38°C) at 200 cm (79 in.). In Figure III-10, temperature profiles from ground surface to 200 cm (79 in.) show temperatures at 2.5 cm (1 in.) above the surface lagging ground surface temperatures by about 25°F (14°C). At the 100 cm (39 in.) level, temperatures are only slightly higher than at 200 cm (79 in.). Similar data is presented in Figure III-11 for the same location during January and February (1957 only).[72] During the period represented, air temperatures from just above the surface to the 200 cm (79 in.) height are uniformly around 50°F (10°C) from midnight until about 0830 hours. At that time, temperatures near the surface begin to rise, reaching a maximum of about 80°F (44°C) until about 1500 hours, when they begin to decrease steadily to 50° to 52°F (10° to 11°C) near midnight. Air temperatures

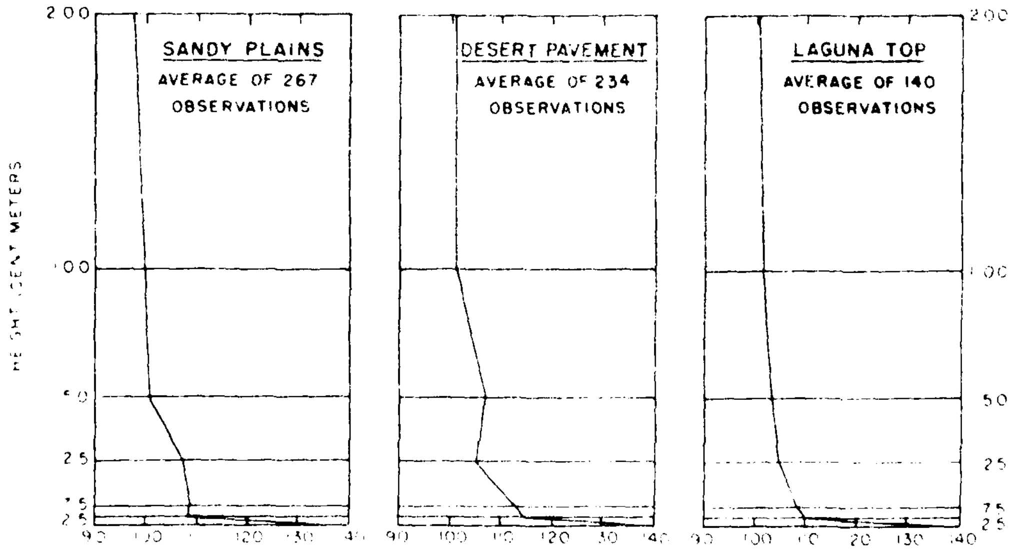


FIGURE III-10. TEMPERATURE GRADIENTS DURING PERIOD OF STRONG INCOMING RADIATION AT YUMA TEST STATION

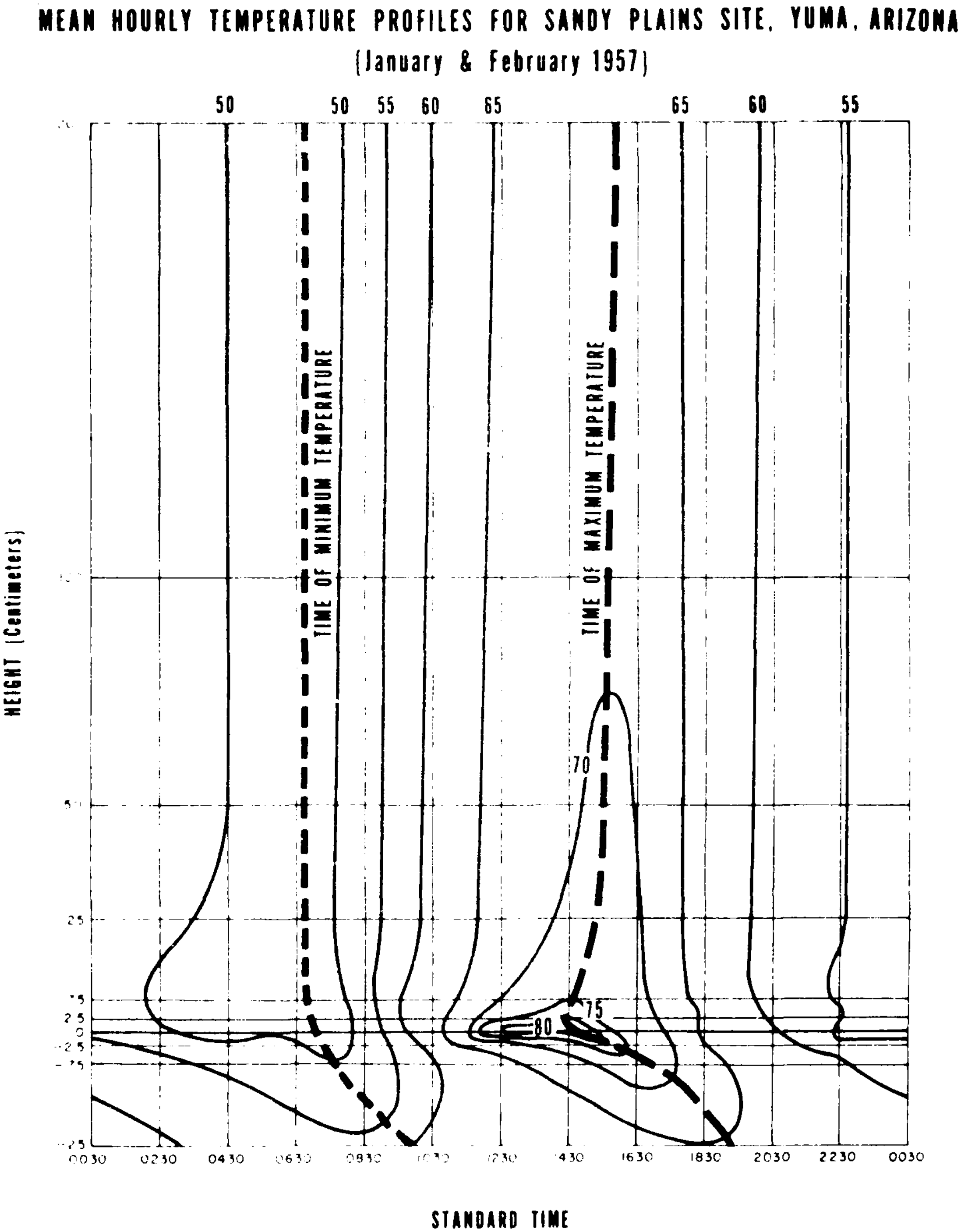


FIGURE III-11. MEAN HOURLY TEMPERATURE PROFILES FOR SANDY PLAINS SITE, YUMA, ARIZONA between 1030 and 1630 hours are differentially lower with increasing distance above the ground surface, reaching a maximum of 65°F (18°C) at 200 cm (79 in.) between 1230 and 1630 hours. From 1800 hours until midnight, temperatures are uniform from just above ground surface to 79 in. (200 cm) above.

(2) Soil and Surface Temperatures

Soil temperatures at several meteorological sites on the Proving Groud have been measured and studied, but findings are much less comprehensive than for atmospheric studies. The summer microclimate study found an absolute maximum surface temperature of 150°F (66°C) and mean maximum temperature of about 138°F occurring at 1430 hours. Surface temperatures reach 130°F (59°C) at about 1200 hours and remain at that level or slightly higher until about 1500 hours. A minimum surface temperature of about 80°F (27°C) occurs from about 0330 to 0530 hours (Figure III-9). The absolute minimum surface temperature is 62°F (17°C), which is also the minimum at 2.5 cm (1 in.) and 7.5 cm (3 in.) below the surface. A later study[73] of 1961, 1962, and 1963 summer data found a maximum soil surface temperature of 155°F (69°C) when air temperature was 110°F (43°C). Of 97 measurements in that study, 3 percent of the surface temperatures were between 150°F (66°C) and 155°F (68°C) when air temperatures were 108°F to 110°F (42° to 43°C), and 78 percent were between 138°F (59°C) and 150°F (66°C) when ambient temperatures were from 105°F to 115°F (40° to 46°C). Both maximum and minimum subsurface temperatures lag behind surface temperatures. In the summer microclimate study, the highest mean hourly temerature at the surface occurred at 1430 hours, the highest mean at a depth of 25 cm below the surface (10 in.) at 2230 hours, 8 hours later. Similarly, the lowest mean surface temperature occurred at 0530 hours, the lowest mean at 25 cm depth at 1230 hours, or 7 hours later.

The winter microclimate study in January and February 1957[74] found absolute maximum surface temperatures of about 110.5°F (43.6°C) and mean maximum temperatures of 84°F (29°C) occurring at about 1400 hours. Maximum surface temperatures reached 80°F (27°C) at about 1230 hours and remained at that level or slightly higher until about 1530 hours. Minimum surface temperatures of about 50°F (10°C) occurred from about 0230 to 0800 hours (Figure III-11). The absolute minimum surface temperature was 29.5°F (1.4°C).

Comparison of the summer and winter microclimate data show that maximum surface temperatures occur at about the same time of the day, with mean summer temperature being about 138°F (59°C), mean winter 84°F (29°C), or roughly 50°F (28°C) lower. Summer and winter minimum surface temperatures also occur at about the same time of day, summer mean minimum about 80°F (27°C), winter about 50°F (10°C) for a difference of only 30°F (17°C).

(3) Sand Dunes

Air temperatures in the sand dune area are slightly higher (2-3°F; 1-2°C) than those on most of the Proving Ground during hours of darkness, and slightly lower (2-4°F; 1.1°-2.2°C) during daylight hours. Soil temperatures follow the same pattern, at 1 inch below the surface being 10° to 12°F (6 to 7°C) higher during nighttime and as much as 14°F (8°C) lower at about noon. The Handbook of Yuma Environment[38] reports a 1952 study of air and soil temperatures at 12 weather observation sites on the Proving Ground and areas off it used for testing, including the Sand Dunes. Average data are presented in tabular form in Table III-1 and in the curves of Figure III-12.

TABLE III 1. COMPARISON OF TEMPERATURE VARIATIONS BETWEEN SAND DUNES AND MOBILITY COMPLEX

Location	Temperatures F, at Time, Hrs											
	0030		0430		0830		1230		1630		2030	
	Ta	Ts	Ta	Ts	Ta	Ts	Ta	Ts	Ta	Ts	Ta	Ts
Sand Dunes	91	100	87	97	88	95	96	107	99	114	95	108
Mob Comp	88	88	84	84	90	90	100	121	101	111	94	96

Ta Air Temperature
Ts Soil Temperature

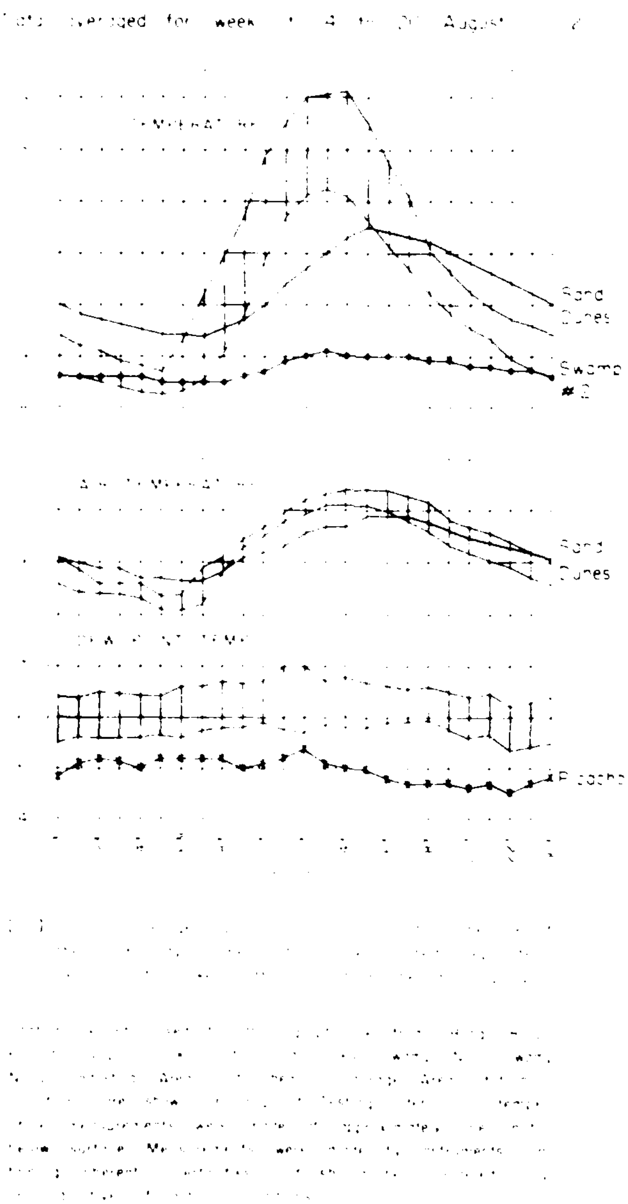


FIGURE III-12. COMPARISON OF SUBSIDIARY CLIMATIC STATIONS, YUMA TEST AREA

(4) Upper Air Temperatures

Upper air temperature data for a total of 13 years is provided by the ASL Yuma Met Team in a radiation study of observations obtained in soundings from the surface to approximately 53,000 feet (16,000 m).[24] Temperatures were measured at 50 mb increments, which are converted to nominal altitude by reference to "U.S. Standard Atmosphere 1976"[25] and tabulated (Table III-2) with corresponding upper air temperatures for each month. One aspect of lower altitude temperatures is the relationship between them

TABLE III-2 UPPER AIR MEAN TEMPERATURE, U.S.A. YPG ASL YUMA MET TEAM

Press	Nominal Altitude		Temperature Mean for Month											
			Jan		Feb		Mar		Apr		May		[illegible]	
mb	ft	m	C	F	C	F	C	F	C	F	C	F	C	F
SFC	300	90	12.1	53.8	14.4	[illegible]	[illegible]	61.[illegible]	20.6	6[illegible]	24.6	76.3	23.3	[illegible]
950	1800	550	13.5	56.3	[illegible]	[illegible]	[illegible]	62.4	20.3	68.5	23.8	74.8	[illegible]	[illegible]
900	3200	980	[illegible]	51.3	[illegible]	[illegible]	14.6	58.[illegible]	17.1	62.8	20.7	69.3	[illegible]	[illegible]
850	4800	1460	8.1	46.6	8.8	47.8	10.1	50.2	13.5	56.3	17.1	62.[illegible]	22.[illegible]	[illegible]
800	6400	1950	5.6	42.1	5.[illegible]	41.3	[illegible]	4[illegible]	9.6	49.3	13.2	55.[illegible]	[illegible]	[illegible]
750	8100	2470	3.1	37.6	2.8	[illegible]	3.5	38.3	5.4	42.6	4.4	48.9	[illegible]	[illegible]
700	9900	3020	0.2	32.4	[illegible]	[illegible]	0.2	32.4	2.4	36.3	5.[illegible]	4[illegible]	[illegible].4	[illegible]
650	11800	3600	3.2	26.2	3.8	25.2	3.4	25.9	[illegible].2	29.8	1.8	3[illegible].2	[illegible]	43.[illegible]
600	13800	4200	7.2	19.[illegible]	7.3	[illegible]	7.6	18.3	5.2	22.[illegible]	2.4	2[illegible]	[illegible].4	34.5
550	16000	[illegible]	11.[illegible]	[illegible].9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].2	[illegible]	[illegible].4	2[illegible]
500	18300	[illegible]	16.8	[illegible].8	[illegible].6	[illegible].2	[illegible]	[illegible]	[illegible]	[illegible]	12.4	[illegible]	[illegible]	[illegible]
450	20800	6340	22.6	8.[illegible]	23.1	[illegible]	23.4	[illegible]	[illegible]	[illegible]	19.4	[illegible]	[illegible]	[illegible]
400	23600	7200	29.1	20.4	29	[illegible].6	29.9	[illegible].8	[illegible]	[illegible]	26.0	[illegible]	[illegible]	[illegible]
350	26600	8110	36.4	33.5	36.8	34.2	37.[illegible]	34.[illegible]	35.[illegible]	31.0	32.6	26.[illegible]	29.5	[illegible]
300	30000	9140	44.4	47.9	44.6	48.3	44.9	48.8	[illegible]	45.4	40.8	41.[illegible]	36.[illegible]	[illegible]
250	34000	10360	52.[illegible]	62.9	52.3	62.1	53.[illegible]	63.4	5[illegible].2	[illegible]	49.8	57.6	45.5	5[illegible].4
200	38700	11800	58.3	72.9	56.6	69.[illegible]	58.[illegible]	72.4	55.5	73.3	57.7	71.9	54.[illegible]	6[illegible].6
150	44700	13620	59.7	75.6	58.[illegible]	73.3	58.9	74.[illegible]	59.8	75.6	60.0	76.[illegible]	62.9	[illegible]
100	53000	16150	64.9	84.8	64.[illegible]	84.[illegible]	63.9	83.[illegible]	64.1	83.4	63.3	81.9	[illegible]	[illegible]

Press	Nominal Altitude		Temperature Mean for Month											
			[illegible]		Aug		[illegible]		Oct		N[illegible]		[illegible]	
mb	ft	m	C	F	C	F	C	F	C	F	C	F	C	F
SFC	300	[illegible]	32.[illegible]	[illegible]	32.4	90.3	29.4	84.[illegible]	23.[illegible]	73.4	16.5	61.[illegible]	22.[illegible]	[illegible]
950	1800	550	31.6	88.9	30.[illegible]	87.4	29.2	84.[illegible]	24.0	75.2	17.[illegible]	63.9	22.[illegible]	[illegible]
900	3200	[illegible]	28.6	83.5	27.7	81.9	26.[illegible]	79.0	20.8	69.4	14.8	58.6	[illegible].2	66.6
850	4800	1460	24.9	76.8	24.0	75.2	2[illegible].2	[illegible]	17.[illegible]	62.8	11.8	53.2	15.9	6[illegible].6
800	6400	1950	20.8	69.4	20.0	68.0	18.1	64.6	13.3	55.9	9.[illegible]	49.2	12.4	54.[illegible]
750	8100	2470	16.5	61.7	15.7	60.3	14.0	57.2	9.7	49.5	6.3	43.[illegible]	8.[illegible]	48
700	900	3020	12.0	53.6	11.3	[illegible]	9.9	49.8	6.[illegible]	43.0	3.3	3[illegible]	6.[illegible]	4[illegible]
650	11800	3600	[illegible].3	45.1	6.8	44.2	5.8	42.4	2.5	36.5	0.0	32.0	[illegible].4	34.5
600	13800	4200	2.5	36.5	[illegible].4	36.3	1.6	34.9	1.4	34.5	4.0	24.8	2.3	2[illegible]
550	16000	4880	2.2	28.0	2.1	28.2	2.8	27.0	6.1	21.[illegible]	8.5	16.7	[illegible].4	18.7
500	18300	5580	[illegible].0	19.4	[illegible].7	19.[illegible]	7.6	18.3	11.3	[illegible]	13.7	[illegible].3	12.5	[illegible]
450	20800	6340	12.3	9.9	11.9	10.6	13.3	8.[illegible]	17.2	1.0	19.5	[illegible]	18.3	[illegible].9
400	23600	7200	18.4	[illegible]	18.1	0.6	19.9	3.8	23.9	17.9	26.0	14.3	24.[illegible]	12.6
350	26600	8110	25.4	13.7	25.3	13.5	27.2	17.0	31.2	24.2	33.2	27.8	32.0	25.6
300	30000	9140	33.6	28.5	33.9	29.0	35.3	31.5	39.1	38.4	41.0	41.9	40.0	4[illegible]
250	34000	10360	43.0	45.4	43.0	45.4	44.1	47.4	47.4	53.3	49.5	57.1	48.[illegible]	55.5
200	38700	11800	53.9	65.0	53.9	65.0	53.8	64.8	55.1	67.2	57.2	71.0	56.3	69.3
150	44700	13620	65.1	85.2	65.3	85.5	64.2	83.6	61.9	79.1	62.5	80.5	61.[illegible]	79.1
100	53000	16150	69.2	92.6	69.3	92.7	69.6	93.3	67.2	88.0	67.0	88.6	66.2	[illegible]44

near its surface and at 1800 ft (550 m). Above 1800 ft (550 m), temperatures decrease consistently with increasing altitude. During the months of April through September, temperatures follow this pattern near the ground to 1800 ft (550 m). During the months of October through December, however, temperatures are slightly higher at 1800 ft than at its surface. Another aspect of interest is a slight shift in maximum annual temperatures with increase in altitude. Near the surface, maximum temperature occurs in July with increasing altitude; however, occurrence of maximum temperature shifts slightly toward August until at 25,000 to 30,000 ft (7600-9000 m) temperatures in these two months become equal.

b. *Insolation*

Like most arid areas, YPG has a low incidence of cloud cover, and receives almost the maximum possible sunshine and insolation. Mean annual cloud cover from sunrise to sunset is 0.25, much of the cloud cover consisting of thin alto-cumulus, alto-stratus, or cirrus clouds that intercept only a small part of the incoming solar radiation.[49] Maximum cloud cover occurs during December through March, minimum during June and September. As can be seen from the lower curve of Figure III-13, mean annual cloud cover is not exceeded from about April through November, with minimums in June and September and intermediate

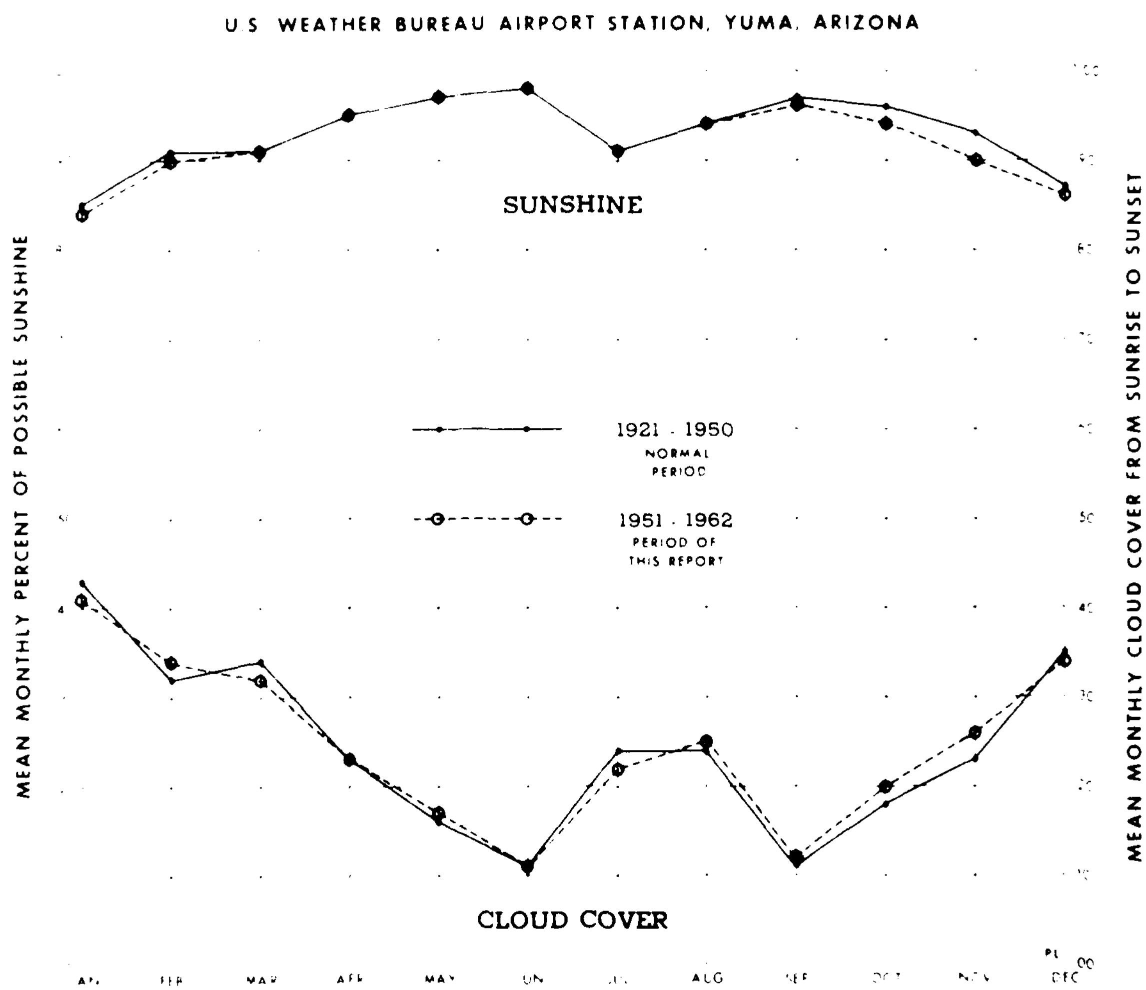


FIGURE III-13. COMPARISON OF SUNSHINE AND CLOUD COVER highs in July and August. The amount of possible sunshine received during the year is high, averaging 93 percent. A maximum of 97 percent or higher is received during May, June, and September (upper curve of Figure III-13), and all months except December receive at least 90 percent of possible maximum insolation.[74] Daily values of insolation received at YPG for the year, with points of daily extraterrestrial insolation by half-months are shown in Figure III-14.[76] Each dot represents the total daily insolation received for each day of record, indicating the general trend and showing the scatter in values at various times of the year. For example, the concentration of dots around 750 ly (Langleys) in May and June indicate consistency in insolation received, which is further exemplified by the limited exceptions below the mean in those months, none below 500 ly in May and only four in June. Mean daily radiation curves are presented in Figure III-15 for the months of May through September, 1952,[38] and indicate that peak insolation values occur between 1200 and 1300 hours in June, slightly less in May, and progressively less in July through September. Rough integration of insolation for June over the time 0600 to 1900 hours totals about 830 ly, which falls within the data for 1952-1962 shown in Figure III-14. In the earlier discussion of soil temperatures, the lag in air temperatures behind soil surface temperatures during daylight hours is pointed out. It is of interest, also, to relate these phenomena to insolation. In Figure III-9, the time of minimum air temperature at 200 cm (79 in.) is about 0530. Minimum surface temperature at zero depth is a minimum from about 0200 to 0700. At about 2.5 cm (1 in.) depth, minimum soil temperature occurs at about 0600. The curves of Figure III-15 are approaching minimum at 0600, the minimum abscissa, but by observation would be minimum for some period before 0530, indicating that insolation would be rising before minimum air and ground temperatures. Air temperature becomes maximum at approximately 1530 hours, maximum surface temperature at zero depth about 1350, at about 2.5 cm (1 in.) depth at 1350 to about 1550. Insolation reaches maximum between 1200 and 1300 hours. Accordingly, the views that air temperature lags ground temperature, and ground temperature lags insolation are confirmed by these data.

c. *Wind*

Surface winds are generally light throughout the year, ranging from 4-12 mph (6-19 kph) 75 percent of the time, although in August 1959, wind speed of 92 mph during a passing thunderstorm was recorded. Monthly mean wind speeds are highest, 9.2 to 9.8 mph (14.8 to 15.8 kph), from March through August. During the remainder of the year, they range from a minimum of 7.6 mph (12.2 kph) in October to a maximum of 8.8 mph (14.2 kph) in December and February (see Figure III-16). Gusts averaging 16-17 mph (26-27 kph) occur during September through February and 21-22 mph (34-35 kph) during March through August. Strong winds may begin at any time of the day and may persist for 24 hours or longer. The strongest gust recorded at the Central Meteorological Station was 71 mph (114 mph) on 20 March 1970. Gusts of 50 mph (80 kph) or higher occurred in five months during the 20-year period 1954-1973, always accompanied by considerable blowing dust. During nighttime hours, from 1800 to 0700, wind speed is 1-2 mph (2-3 kph), picking up rapidly to 5-7 mph (8-11 kph) after sunrise and remaining at approximately that level during the day.[46] These generalities apply to plains areas of lower elevation (about 400 ft) such as the Mobility Complex. In the "mountains", as exemplified by the North Laguna Mountains, wind speeds fluctuate similarly during July and August, but from about 5 mph (8 kph) to 13 mph (21 kph). During January and February, however, they remain relatively constant at 6-8 mph (10-13 kph) throughout the day and night.[72]

During late winter and early spring, prevailing winds are from the north; strong gusty winds from the north and northwest may occur at any time of the day and may persist for 24 hours or longer. During the summer months, prevailing winds are from the southwest. Numerous small mountains and valleys may affect local wind directions.[70]

YUMA TEST STATION, 1952-1962

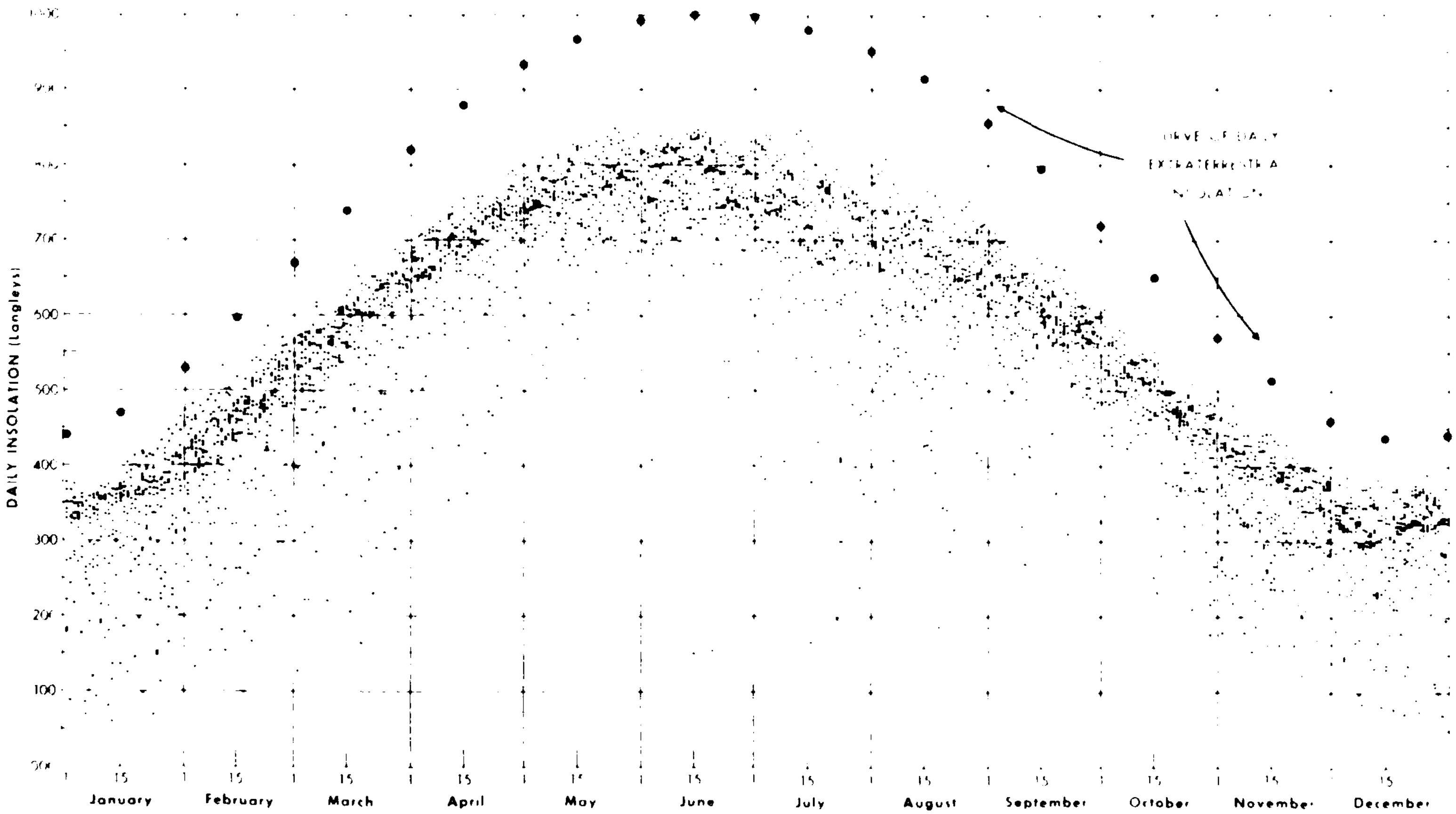
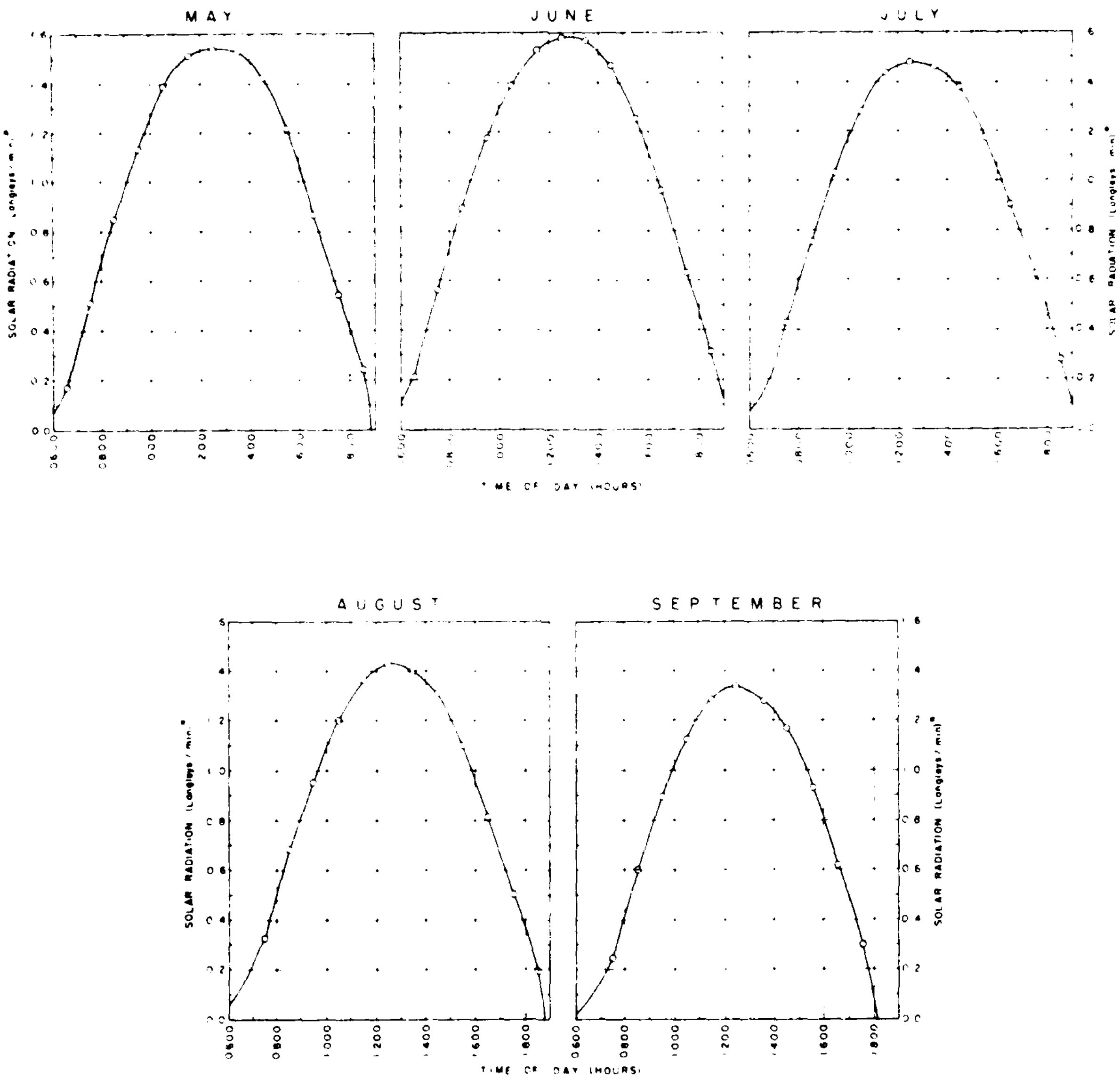


FIGURE III-14. DAILY VALUES OF INSOLATION

MEAN DAILY RADIATION CURVES
YUMA TEST STATION, 1952



DATA ARE FOR SOLAR RADIATION MEASURED ON A HORIZONTAL SURFACE BY AN EPPLEY PYRHELIOMETER

To compute the average total for any hour, multiply the mid-point by 60

* One Langley = 1 gm-cal / cm²

FIGURE III-15. MEAN DAILY RADIATION CURVES

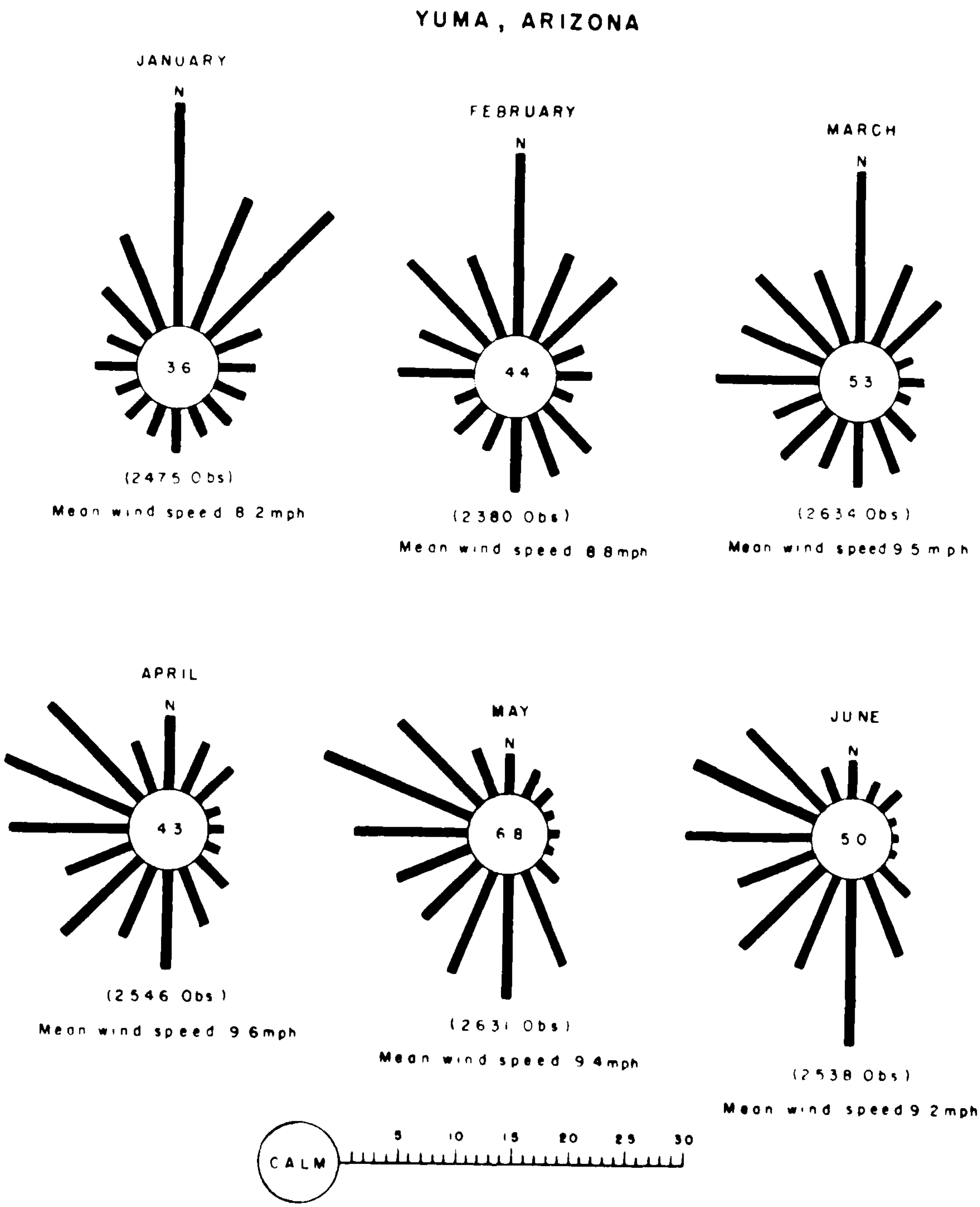


FIGURE III-16. SURFACE WINDS – PERCENTAGE FREQUENCY OF OCCURRENCE BY DIRECTION

YUMA, ARIZONA

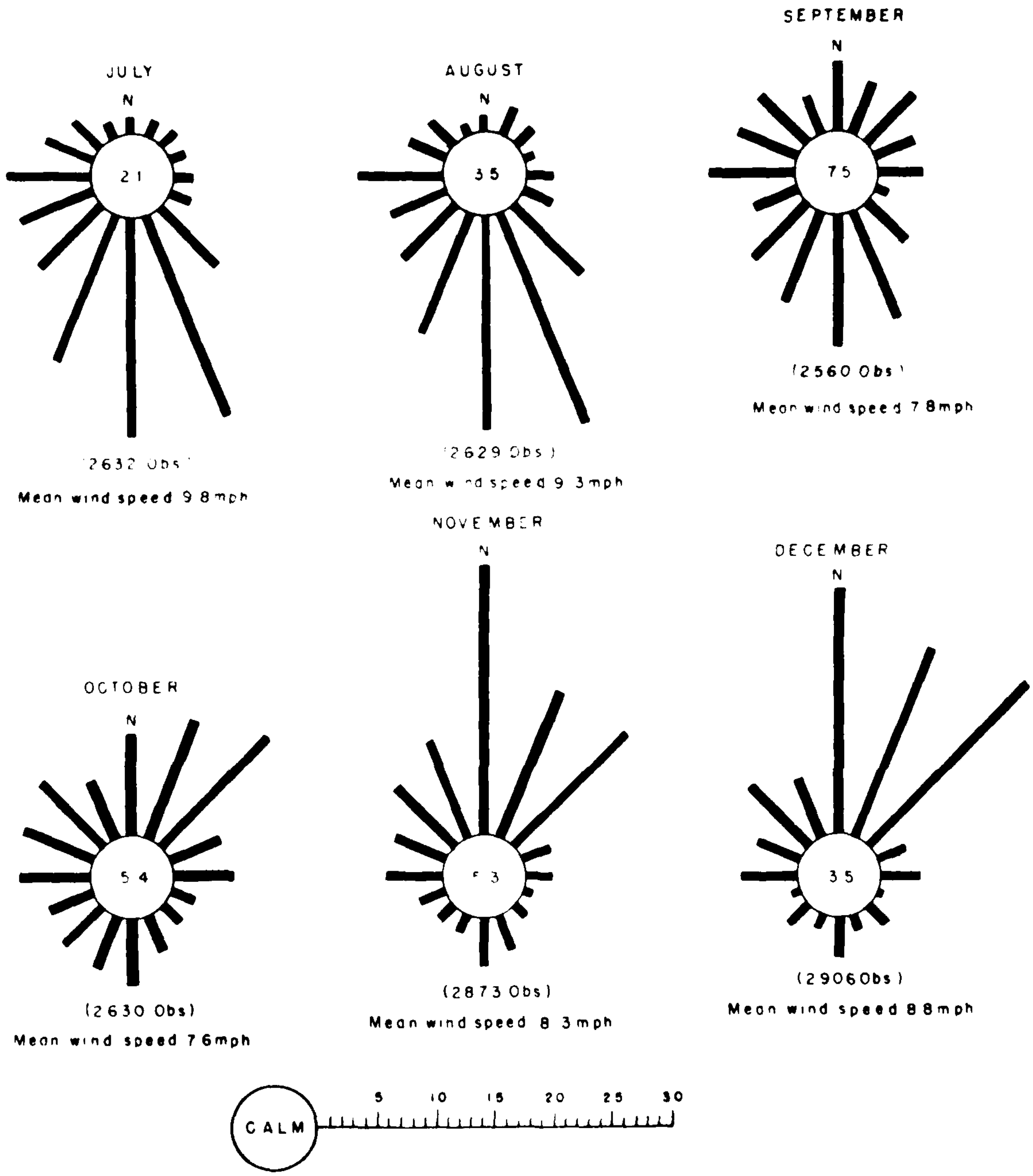


FIGURE III-16. SURFACE WINDS – PERCENTAGE FREQUENCY OF OCCURRENCE BY DIRECTION (Cont'd)

d. *Sand and Dust*

Official records for YPG document airborne sand and dust principally in terms of visibility distances and airborne particle density at standard meteorological height.[38] Particle size and petrographic analysis of soil samples from specific areas suggest probable characteristics of the particulate matter when sand or dust storms are encountered. Because of soil and wind variables at diverse locations on the Proving Ground, occurrence of blowing sand or dust and nature of airborne particles also vary. According to Bagnold,[7] wind velocity of 11 mph (18 kph) at 10 cm (4 in.) above the surface is just strong enough to set in motion grains of sand on the ground. Clements, et al,[58] observes: "Winds in excess of 30 miles per hour are required to create sand and dust storms in the desert in all areas except for regions in the lee of sand dunes and sandy areas . . . Winds whose velocity is greater than 30 miles per hour are rare, and as a consequence sand and dust storms during the course of a year are not common events. The frequency of strong windstorms in the United States desert area is certainly not more than three or four a year." Occurrences of gusts above 50 mph related in the preceding section indicate that significant occurrences of blowing sand and dust are relatively infrequent on the Proving Ground. Tables III-3, III-4, and III-5, pertaining to atmospheric visibility and particle density, may be similarly interpreted. Unofficially, YPG experiences three to four dust storms per year; amounts of sand on the Proving Ground are insufficient for sand storms to be of consequence. In general, however, tests disturbing ground surface dust are a more likely cause of airborne dust than natural causes (Figure III-17).

e. *Relative Humidity and Dew Point*

Mean monthly dew point temperatures are pictured in Figure III-18, mean monthly early morning and late afternoon relative humidities in Figure III-19. Diurnal dew point and humidity data for two summer days are represented in Figure III-8. Dew point is lowest during winter months, ranging from 32° to 35°F (0-2°C), increasing progressively until June when it begins an abrupt rise, reaching a maximum of 64°F (18°C) in August. Thereafter, it falls steadily and rapidly, reaching minimum again in November and winter months following. Relative humidity at 0530 hours (Figure III-19) reflects the abrupt rise in atmospheric moisture during June through August and its decline in following months until November. A maximum of 65 percent is reached in August and a low of 52 percent in November, ranging around 55 percent from December through June. The lower curve, showing mean relative humidities at 1730 hours from about 15 percent in May and June to 36 percent in December, represents Yuma's, and other deserts, characteristically low relative humidity. Data for Figure III-8 (ambient temperatures section) were selected from three years' meteorological observations. They were selected as days of maximum and minimum atmospheric moisture with similar air temperature profiles. As such they may be considered roughly representative for the months of June and July, but not absolute nor mean maximum or minimum. Viewed from this standpoint, the dew point on the day of high atmospheric moisture ranged generally downward during the day from about 65°F (18°C) at 0100 hours to about 50°F at 2400 hours, with excursions upward and downward from that trend. On the day of low atmospheric humidity, the dew point ranged from about 25°F (-4°C) to 21°F (-6°C) between 0100 and 2100 hours, with a high of 34°F (1°C) between 0400 and 0800 hours and another of about 50°F (10°C) from 2200 to 2400 hours. Relative humidity for the same day followed the dew point pattern, varying from about 9 percent at 0100 hours to 4 percent at 2100 hours, with an upward excursion between 0100 and 1000 hours, reaching a maximum of 17 percent at about 0600. A second high of about 30 percent occurred from 2200 to 2400 hours. The sharp increases in both dew point and relative humidity at this time are attributed to advection of moist air from the Gulf of California as a small, closed low-pressure area developed over Yuma.

TABLE III-3. MEAN WEEKLY DUST COUNT FOR SPECIFIED HOURS, YUMA TEST STATION, YUMA, ARIZONA

Week	Hour 0800	1200	1600	2400
1 July - 5 July	546	716	764	696
6 July - 12 July	560	680	656	489
13 July - 19 July	410	538	471	608
20 July - 26 July	510	729	677	597
27 July - 2 Aug	654	817	871	859
3 Aug - 9 Aug	767	1083	929	657
10 Aug - 16 Aug.	549	773	910	676
17 Aug - 23 Aug.	482	736	697	713
24 Aug. - 30 Aug	473	735	778	557
31 Aug - 6 Sept	615	682	777	447
7 Sept. - 13 Sept	829	753	944	953
14 Sept. - 20 Sept	791	907	695	790
21 Sept - 27 Sept.	605	698	670	576
28 Sept. - 3 Oct	536	644	734	536
Average for Period	594	749	755	654

*Data obtained from the Signal Corps Weather Station (Bldg. 822), Yuma Test Station. Samples of air were collected at a height of 2 meters from the ground. Amounts are number of particles (in thousands) per cubic foot of air.

TABLE III-4. VISIBILITY, YUMA, ARIZONA

Visibility	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 to 1/8	0.1	0.2	*	0.0	0.1	0.0	0.0	0.1	*	0.1	0.0	0.1
0 to 1/4	0.2	0.2	0.1	0.0	0.1	0.0	0.0	0.2	*	0.2	0.0	0.4
0 to 1/2	0.2	0.3	0.3	0.1	0.2	0.1	0.1	0.2	*	0.3	0.1	0.6
0 to 3/4	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.2	*	0.3	0.2	0.6
0 to 2-1/4	0.7	0.4	0.7	0.7	0.5	0.2	0.4	0.3	0.1	0.4	0.3	0.9
0 to 2-1/2	0.7	0.5	0.7	0.7	0.5	0.2	0.4	0.3	0.1	0.4	0.3	0.9
0 to 6	1.9	1.2	1.6	2.2	1.3	0.5	0.8	0.8	0.3	0.7	0.8	1.6
0 to 9	2.6	2.1	2.2	2.6	1.7	1.1	1.3	1.4	0.5	1.0	1.2	2.2
10 and Over	97.4	97.9	97.8	97.4	98.3	98.9	98.7	98.6	99.5	99.0	98.8	97.8

*Indicates less than 1/2 of 1/10 percent

The climatic data presented in the above table were obtained from the Air Weather Service, USAF

All data were machine-computed and are subject to small rounding errors

TABLE III-5. OBSTRUCTIONS TO VISION (VISIBILITY < 1 MILE) YUMA, ARIZONA

Obstructions to Vision	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fog	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Smoke and Haze	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blowing Snow and Dust	0.1	0.1	0.2	0.2	0.2	*	*	0.1	*	0.3	0.1	0.2
Precipitation and Drizzle	0.0	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cause Unknown	*	0.0	0.1	0.0	0.0	0.0	*	*	0.0	*	0.1	0.1
Total	0.2	0.3	0.3	0.2	0.2	*	0.1	0.2	*	0.3	0.2	0.7

*Indicates less than 1/2 of 1/10 percent.

The climatic data presented in the above table were obtained from the Air Weather Service, USAF

All data were machine computed and are subject to small rounding errors

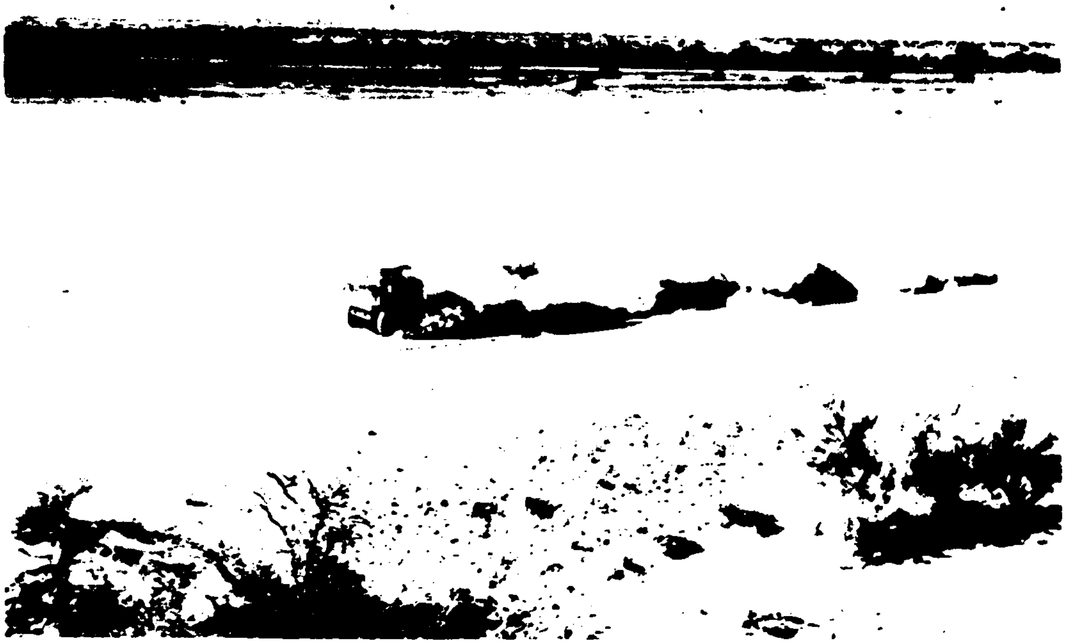
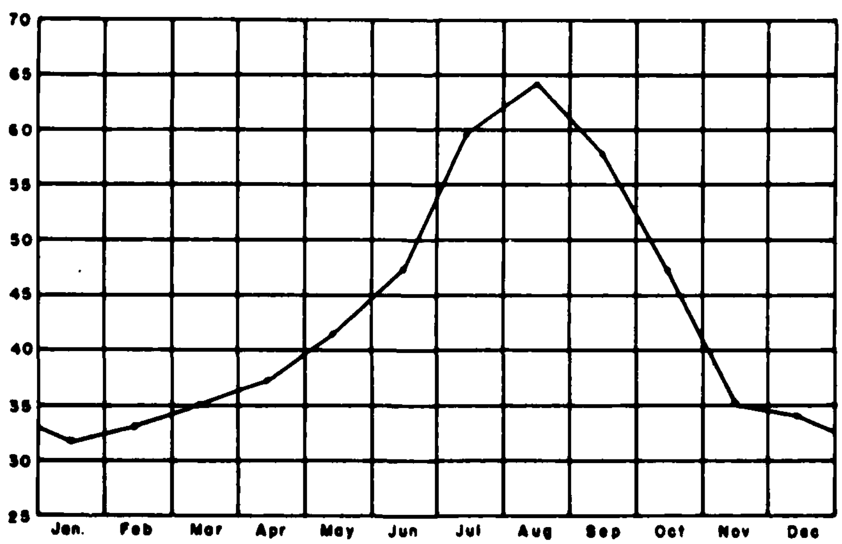


FIGURE III-17. M792 OPERATING ON DUST COURSE, MUGGINS MESA

YUMA, ARIZONA



Dewpoint temperature data were obtained from U.S. Weather Bureau Monthly Climatological Summary with Comparative Data (January through December 1948) for Yuma, Arizona. Length of record was not indicated.

FIGURE III-18. MEAN DEW POINT TEMPERATURE

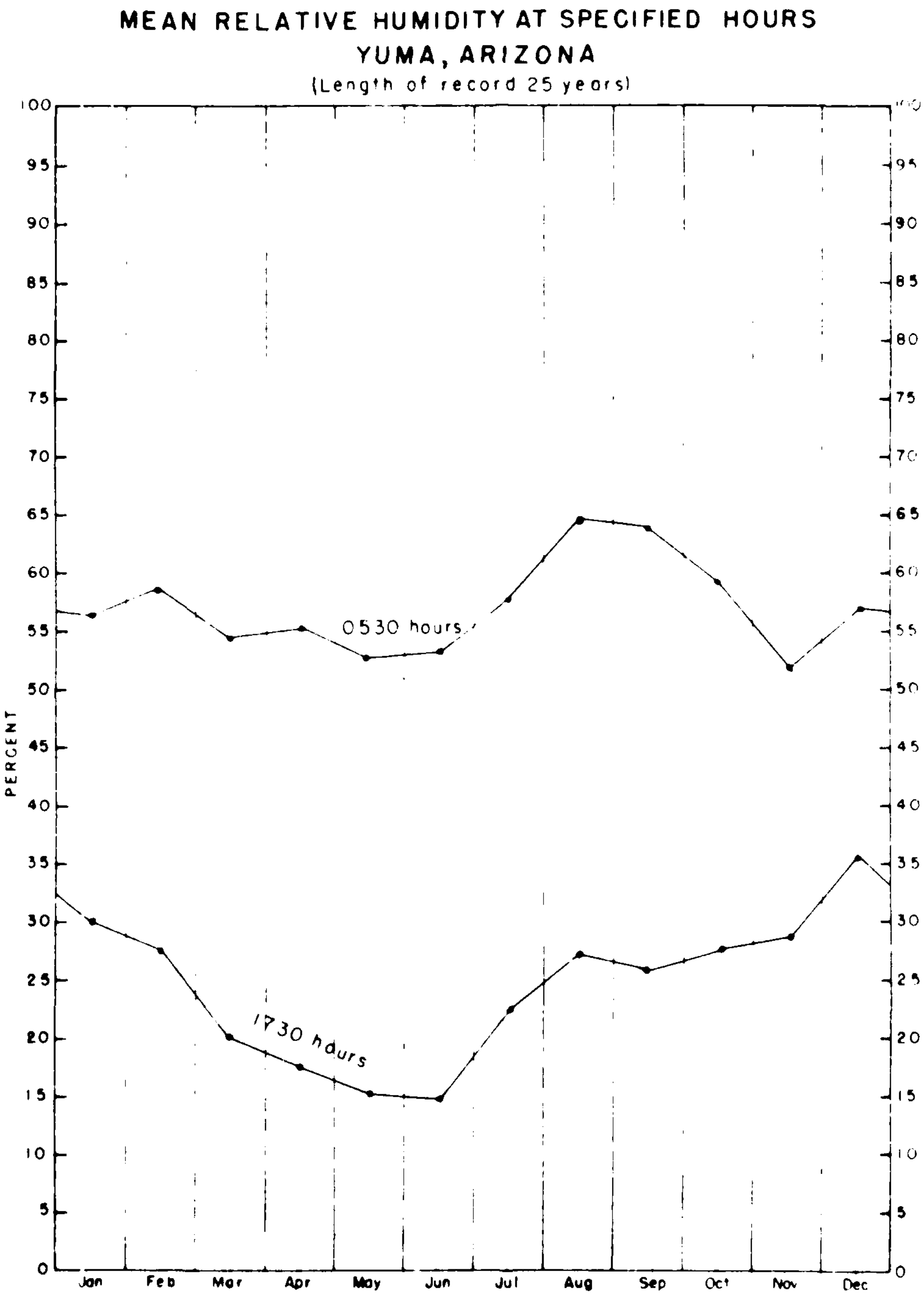


FIGURE III-19. MEAN RELATIVE HUMIDITY AT SPECIFIED HOURS *f. Precipitation*

To some extent, Trewartha's statement concerning desert precipitation is applicable to Yuma: "It is a general rule, worthy of memorization, that dependability of precipitation usually decreases with decreasing amount."[23] Yuma's annual rainfall averages 3.38 in. (8.59 cm), yet during 1905 and 1906, rainfall in the Colorado and Gila River watersheds caused the Colorado to overflow into the Salton Trough and restablish the Salton Sea. During a period of almost 30 years, records of mean frequency of thunderstorms at Yuma show none from November through June, one day in October, two days in September, three in July, and four in August.[35] Before construction of Interstate Highway 8, on one occasion thunderstorms, on two successive days in August, washed out approaches to a bridge on U.S. Highway 80 between Gila Bend and Yuma over what was normally a dry wash. In contrast, every month of the year, in almost 30 years, has experienced no measurable rainfall.[35] Figure III-20 shows minimum, mean, and maximum rainfall for each month, plus the greatest precipitation in 24 hours and illustrates the extremely low rainfall during April through July. Table III-6 shows the frequency of occurrence of rainfall from zero to 2.5 in. (6.4 mm) as recorded over a 25-year period. May and June stand out as the driest months, with about 98 percent of the days in that time having experienced no rainfall. In May, only 4 days experienced more than a trace of rain, the greatest precipitation being less than 0.25 inches. In June, 3 days experienced more than a trace, the highest rainfall being less than 0.10 in. (2.5 mm) on each of the two days.

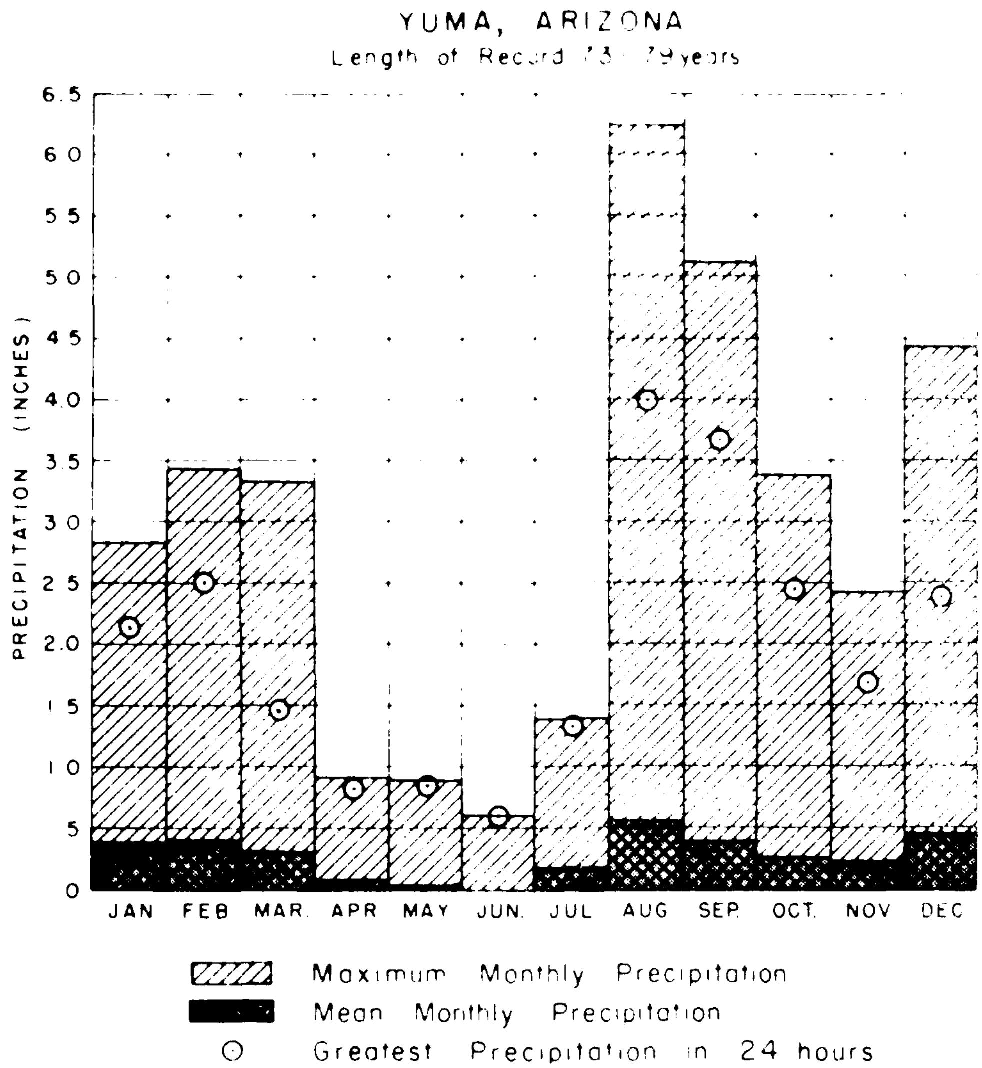
g. Ozone

During the early 1950's, Yuma was considered to be one of the areas of high ozone concentration in the continental United States and, hence, a candidate area for static tests of ozone effects on natural and synthetic elastomers. In the Federal government synthetic rubber program at that time, "ozone cracking" in tire sidewalls was of some concern, as was possible deterioration of military tires in storage, from effects of ozone. Since then, studies of atmospheric ozone and its effects at ground level have indicated negligible effects on the unstressed elastomers. For other purposes, however, current levels of ozone concentration are of interest. As of 1977, the atmospheric concentration measured at the City of Yuma Monitoring Station was 10 $\mu g/m^3$ 1 hr maximum. EPA primary and secondary standards are 160 $\mu g/m^3$. Because of the large expanse of the Proving Ground ozone concentration may vary from site to site and may differ from that at the monitoring station in Yuma. For tests in which ozone exposure is a factor, these possible variations should be recognized and arrangements should be made for ozone monitoring at the test site.

2. Terrain

a. General

The Proving Ground includes a variety of terrain features. Rugged, deeply dissected, commonly linear bedrock mountains alternate with gravelly and sandy lowlands cut by steep-sided washes.[46] The desert plains of the Proving Ground rise from about 300-400 ft elevation along the southern boundary of the reservation and from about 200 ft along the Colorado River near the Main Post area to 1500 ft along the northestern boundary, to 1000 ft northwest at the eastern tip of that arm of the "U".[45] Mountain ranges and small mountain groups, in effect, are superimposed on the basic plain and include Tank Mountains and Palomas Mountains in the eastern arm, Dome Rock Mountains and Trigo Peaks in the extreme northern end of the western arm, Trigo and Chocolate Mountains south of them, Middle mountains near the base of the west-



Minimum Monthly Precipitation in each month is [illegible]

FIGURE III-20 PRECIPITATION REGIME

TABLE III-6. FREQUENCY OF OCCURRENCE OF PRECIPITATION

Precipitation in	Jan Days	Jan %	Feb Days	Feb %	Mar Days	Mar %	Apr Days	Apr %	Mar Days	Mar %	Jun Days	Jun %
None	681	87 9	587	83 1	705	91 0	709	94 5	762	98 4	732	97 6
Trace	36	4 6	56	7 9	36	4 6	27	3 6	9	1 2	15	2 0
01	8	1 0	7	1 0	4	0 5	3	0 4	1	0 1	0	0 0
02 05	17	2 2	18	2 6	9	1 2	3	0 4	1	0 1	1	0 1
06 10	12	1 6	12	1 7	1	0 1	3	0 4	1	0 1	2	0 3
11 25	11	1 4	17	2 4	12	1 6	2	0 3	1	0 1	0	0 0
26 50	6	0 8	6	0 9	4	0 5	1	0 1	0	0 0	0	0 0
51 1 00	3	0 4	2	0 3	3	0 4	2	0 3	0	0 0	0	0 0
1 01 2 50	1	0 1	1	0 1	1	0 1	0	0 0	0	0 0	0	0 0
Total	*58/775	100	63/706	100	34/775	100	14/750	100	4/775	100	3/750	100

Precipitation in	Jul Days	Jul %	Aug Days	Aug %	Sep Days	Sep %	Oct Days	Oct %	Nov Days	Nov %	Dec Days	Dec %
None	689	88 9	655	84 5	692	92 3	712	91.9	690	92 0	672	86 7
Trace	45	5 8	64	8 3	22	2 9	30	3 9	27	3 6	44	5.7
01	9	1 2	4	0 5	3	0 4	2	0 3	4	0 5	10	1 3
02 05	13	1 7	15	1 9	[illegible]	0 9	8	1 0	12	1 6	14	1 8
06 10	5	0 7	11	1 4	5	0 7	8	1 0	8	1 1	12	1 5
11 25	8	1 0	11	1 4	10	1 4	5	0 6	5	0 7	14	1 8
26 50	4	0 5	6	0 8	4	0 5	4	0 5	4	0 5	3	0 4
51 1 00	1	0 1	6	0 8	4	0 5	4	0 5	0	0 0	6	0 8
1 01 2 50	1	0 1	3	0 4	3	0 4	2	0 3	0	0.0	0	0 0
Total	41/775	100	56/775	100	36/750	100	33/775	100	33/750	100	59/775	100

*Number of days with precipitation greater than a trace, *in relation* to the total number of days for the period of record

ern arm, and Laguna Mountains (Figure III-21) in the extreme southwestern sector. Along the base of the "U", Castle Dome Mountains extend southeastward from the KOFA Refuge, and Muggins Mountains and Red Bluff Mountain are located along the southern margin of the reservation. Peaks range from about 1080 ft in the Laguna Mountains in the southwest of the area to 2152 ft in the Tank Mountains in the northeast, 2822 ft in the eastern Chocolate Mountains, and 2878 ft in the eastern Dome Rock Mountains. Intermediate peaks rise to 1800-1900 ft in the eastern Muggins Mountains, 1560 ft in the Castle Dome Mountains, Mojave Peak to 2771 ft in the Chocolate Mountains, and to 2600 ft in Trigo Peaks. Maximum local relief ranges from 980 ft (southern Laguna Mountains to the Colorado River) to 2578 ft (Dome Rock Mountains to the Colorado River).

b. *Relief*

"Although the total relief of each of the mountain ranges on the Proving Ground is relatively low, the combination of steeply faulted margins, extensive intra-range faulting and jointing, and severe mechanical weathering has produced impressively rugged topography, with slopes locally exceeding 40°.

Relief of the unconsolidated desert plain materials ranges from several inches on the extensive undissected gravelly piedmonts (desert pavements) and flat-floored washes, through a mean of about 7

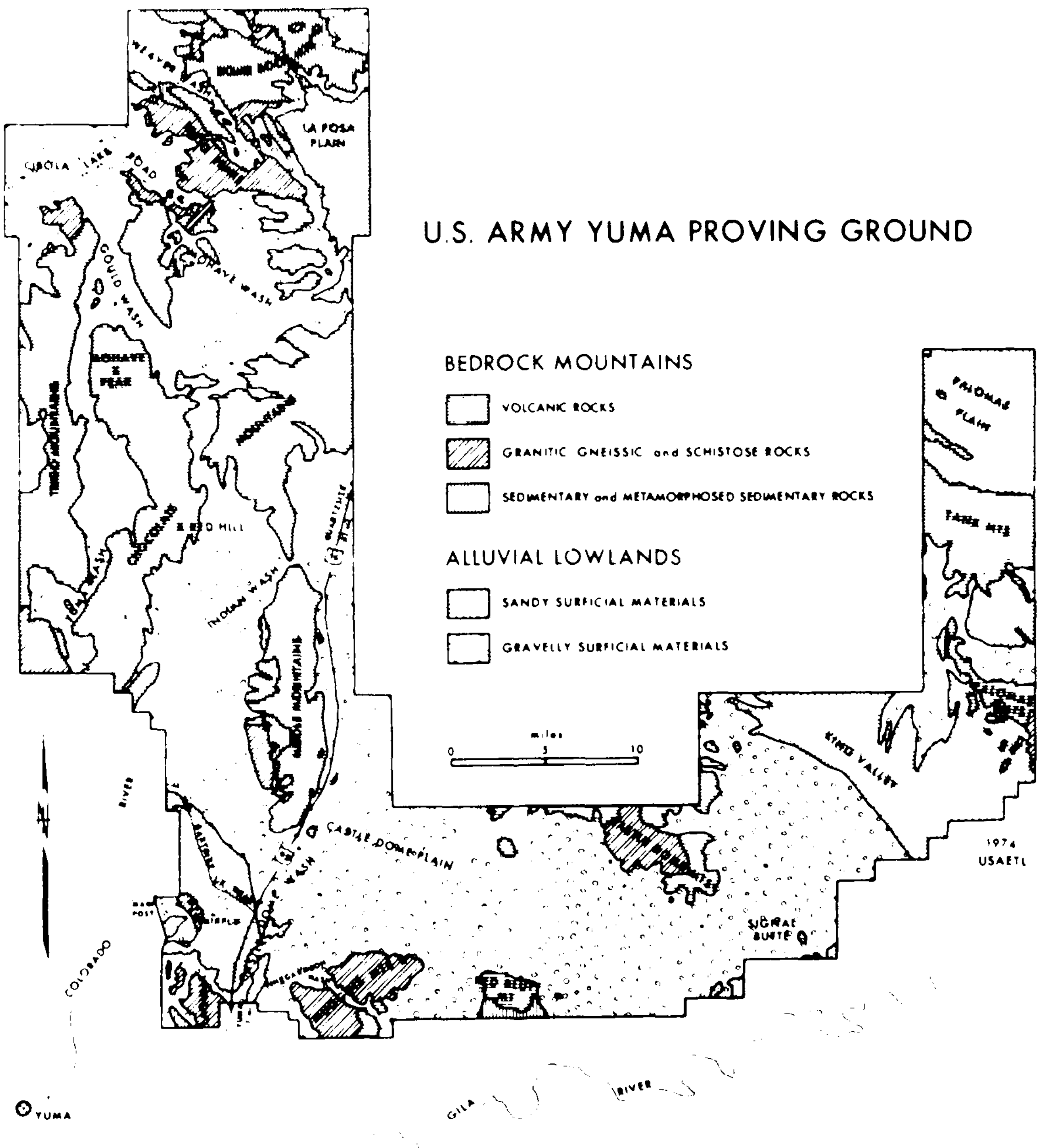


FIGURE III 21. GENERALIZED DISTRIBUTION OF SURFACE MATERIALS feet in the dissected sandy hills, to as much as 51 feet in the highly dissected gravelly piedmonts fringing portions of all the mountain masses."[45]

c *Bedrock Mountains*

Bedrock mountains have been relatively little used and are of minor importance for material testing. Future testing at the Proving Ground will require more detailed consideration of bedrock characteristics. If, for example, high-energy blast tests are conducted, the possibility of seismic shocks of hazardous intensities must be considered from the standpoint of densities, elasticities, and structures of the bedrock associations. Infra-red light amplification and laser target discrimination and marking must be considered with regard to thermal properties and reflectances of bedrock backgrounds. Properties of rocks, as they relate to the spectral frequencies of various sensors,[45] must be considered in using remotely sensed detection of camouflage.

Bedrock occupies about one-third of the Proving Ground surface. Volcanic rocks are strongly predominant, making up three-fourths of all exposed bedrock. They are most abundant in the western areas (Chocolate, Trigo, and Middle Mountains) and in the northeast (Tank and Palomas Mountains). Granitic, gneissic, and schistose rocks are next in abundance, occurring principally in the northwest and along the southwestern part of the Proving Ground. Minor outcrops of intrusive rocks and slightly consolidated or indurated alluvial and colluvial materials are common in and around the bedrock mountains. Sedimentary and metamorphosed sedimentary rocks make up most of the northernmost part of the Proving Ground and small areas elsewhere. Evidence suggests that the Castle Dome Plain is underlain at relatively shallow depth by bedrock — that the basin beneath it is not deeply filled with alluvium as is common in other areas. Bedrock was encountered at the 190-ft depth in a well at Castle Dome Heliport in the northwestern area of the plain.

d *Alluvial Lowlands*

Alluvial lowlands are the principal areas used for testing at YPG. Gravelly and sandy surfaces are the "hard" and "soft" ground, respectively, for impact testing of material delivered or emplaced by aircraft, artillery, or hand. The rolling hills, sandy plains, desert pavements, washes, and gullies are the land forms most suitable for mobility testing and are representative of the terrain most frequently encountered in desert military operations.[9]

e *Gravelly Surfaces*

Gravelly materials predominate in all plains areas except on the La Posa Plain (the northeastern edge of the western arm of the Proving Ground); southwestern areas, including the drop zones; Laguna Army Airfield Complex; the Mobility Complex; adjacent land south to the Laguna Mountains; and King Valley.

Gravelly plains of nearly flat relief are commonly surfaced with "desert pavement" (Figure III-22). Pebble to cobble size gravel forms a continuous single-fragment-thick sheet to protect the underlying materials from further erosion and deterioration. Quite frequently, the exposed surface of the gravel has a dark patina of "desert varnish" if age and composition are appropriate to its formation. The varnish is a superficial, dark-brown-to-black stain, predominantly of iron and manganese oxides, formed on the upper surface of gravel by the combined effect of condensed atmospheric moisture and action of biological agents

FIGURE III-22. DESERT PAVEMENT

on the gravel surface. The soil profile beneath the pavement is described as follows, applicable specifically to the "pavement" at the northwest corner of the Muggins Mountains (site of the Dust Course):[45]

"The surface materials are mostly pebble size (1 to 1-1/2 inches in diameter), mostly of gneissic composition and darkly varnished. There are occasional cobbles to 5 inches in diameter.

"Under the surface fragments is a thin 'film' of grayish to reddish-brown, silty, very fine sand seldom more than one-eighth inch thick.

"Blowing or brushing away the sandy film reveals slightly rounded 'caps' of friable, vesicular, roughly hexagonal columnar soil peds about 1-1/2 inches in diameter extending down 3 or 4 inches . . . The peds are composed of light grayish-to-reddish-brown clayey, very fine sand with no admixed stony fragments.

"Under the ped layer, which is quite uniform in thickness and which has a clearly defined lower surface, is a 6- to 8-inch thick layer of loose, almost 'fluffy', reddish-to-grayish-brown granular, assorted sands with minor silt and clay and very little gravel.

"Below the loose layer, with a transition through only a short distance, are the generally grayish, sandy gravels that are the parent materials of the profiles developed above them.

"The soil profile characteristics affect several aspects of testing and tactical use of desert pavements; moving vehicles squeeze the sandy film up around surface stones and thus leave a clear, temporary record of their passing. Bearing support for vehicles is provided by the combination of armoring surface materials and the firm ped layer. These elements of the profile, however, are inadequate to support heavier vehicles on multiple passes; once the layers are broken, the vehicle sinks abruptly to the base of the fluffy layer, with consequent rutting. Any disturbance of the surface becomes a nearly permanent scar that is difficult to camouflage. The ped layer is the principal source of dust or disturbed desert pavements, contributing the materials by means of which 'signatures' of moving vehicles and artillery impacts are evident. The dust deteriorates polished surfaces, filters, seals, and closely machined mating surfaces. The essentially gravelly composition of materials under desert pavements makes such areas the 'hard' ground desert for artillery fuze functioning tests, airdrop delivery, and foxhole-emplacement device tests."

f. Sandy Surfaces

"Sandy plains occur in the La Posa and Palomas Plains, in King Valley, and in the area north of the southern Laguna mountains (Figure III-21). They are developed on thick, predominantly sandy deposits whose uppermost materials have been redistributed by wind and water. Layers and lenses of clay and fine gravels occur at depth, but sands and silts predominate. A new well (1972) in King Valley near Mesquite Jim Well, logged to 1105-ft depth, intersected only one gravel layer (at 15-30 ft depth); the remainder of the hole was in sand, silt or clay.

"On the plains and in King Valley, relief is low, consisting mainly of narrow, vertical-sided drainages seldom deeper than 3 feet in the finer materials, and of wide, shallow swales in areas away from the active valley axes.

"Lag pavements (Figure III-23), commonly varnished, occur throughout the sandy plains area north of Laguna Mountains and border other areas of the sandy plains. Lag pavements

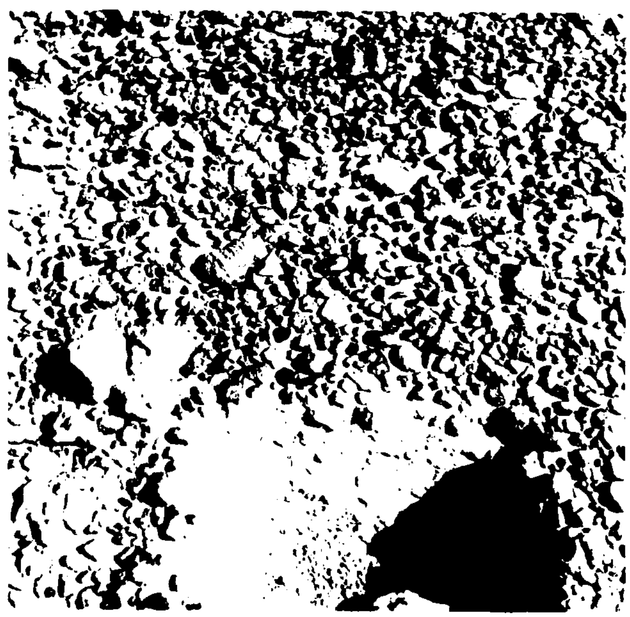


FIGURE III-23. LAG PAVEMENT

differ from desert pavements primarily because the materials under them affect testing and military operations differently and because their mode of origin is different. They are less extensive than desert pavements because they are derived from thin, commonly discontinuous layers and lenses within predominantly sandy or silty deposits, in areas formerly susceptible to rapid erosion by flooding. Their surface is usually slightly higher than adjacent, nonpavemented finer materials.

"The sandy plains are easily trafficable for low ground-pressure vehicles, but the loose, fine-grained surface materials and narrow, vertical-sided drainages can slow or hinder movement of wheeled vehicles with standard tires. The sandy plains areas are the 'soft' areas desired for certain artillery impact and airdrop delivery tests. Dust on undisturbed areas is raised by vehicle and helicopter movements, but to a lesser extent by helicopters than might be expected because a very thin, friable crust armors the surface."

3. Petrographic Data

Petrographic analyses of soil samples from various vehicle test courses are presented in Table III-7.

4. Vegetation[2]

a. *General*

Vegetation in the Yuma Test Area varies from the sparse, typically desert types of the sand plains, gravel surfaces, and hills to the dense, moisture-loving plants of the river bottomlands. The chief criteria used for classification are plant size and vegetation density because these, rather than floristic distinctions, are a chief concern in military planning and testing. Camouflage, concealment, obstruction to movement, and abrasion are all related to these basic factors of size and density. Vegetation density is defined as the percentage of the ground area covered by the downward vertical projection of the foliage. The vegetation types thus distinguished are dense marsh plants, cultivated crops, dense shrubs and trees, sparse shrubs, and very sparse shrubs. This classification considers only the perennial vegetation; for a brief period in the spring, there is usually a relatively abundant growth of low annual herbs and grasses covering much of the ground.

b. *Dense Vegetation*

The "dense" types are all associated with the silt bottomlands adjacent to the Colorado and Gila Rivers. In these lands, the ground water table is frequently close enough to the surface to provide ample water for a relatively dense growth of trees and shrubs, and the soil is sufficiently fertile to permit the cultivation of farm crops under irrigation. The dense marsh plants are submerged much of the time. These plants are frequently found where silt is being deposited behind a dam or where shallow overflow waters from the river form an intermittent lake or marshland. In the dense types, the characteristic color of the landscape is that of the vegetation—usually grayish green where arrowweed or tamarisk brush is dominant.

c. *Sparse Vegetation*

In the types designated "sparse" or "very sparse", density never exceeds 30 percent, and the color of the landscape is determined largely by the color of the ground rather than that of the vegetation,

TABLE III 7. SOIL PROPERTIES, VEHICLE TEST COURSES

Sample Number	Location	Percent Abrasive	Principal Abrasive Minerals	Percent Nonabrasive	Principal Nonabrasive Minerals	Particle Shape	Remarks
2	Vapor Lock Gulch Coarse	23	Quartz	77	Carbonate	Subround to Angular	Only particles above 3 microns (u) included here. Particles below 3 u have much higher abrasive content
9	Tank Hill Course High Hills	13	Quartz	87	Clay, Gypsum Chlorite	Angular to Sub angular except round carbonate	Same as above
15	Tank Level Cross Country Wash	38 7	Quartz Amphibole Magnetie	61 3	Clay, Gypsum Carbonate Carbonate Mica	Abrasive Grains Angular to sub angular, nonabr., round to subround	Same as above
16	Tank Level Cross Country Foot Hills	18 5	Quartz	81 5	Carbonate, Clay, Mica Mica	Abrasive Grains subround to sub angular	Same as above
22	Truck Cross Country Light Volcanic	9 5	Quartz Feldspar	90 5	Clay, Carbonate	Round to subround	Sam as above. Clay occurs in aggregate that if separated would increase the nonabrasive percentage
23	Truck Cross Country Dark Volcanic	2	Quartz Feldspar	98	Clay, Carbonate	Angular, Fibrous to subround	See remarks under sample 2 Composed almost entirely of clay and carbonate, much of it iron stained
2	Vapor Lock Gulch Coarse	71	Quartz	29	Clay, Gypsum	Round to subround	
9	Tank Hill Course High Hills	77	Quartz	23	Clay, Gypsum	Hard Grains – Subangular to Angular, Nonabr., Round	Mineral assemblage typical of altered gneiss – see Yuma rock samples R 2 and R 3
15	Tank Level Cross Country Wash	77 6	Quartz	22 4	Clay, Iron Stained grains Gypsum	Subangular Round	Abrasive grains include Magnetite, Fe_3O_4
16	Tank Level Cross Country Foot Hills	51 5	Quartz	48.5	Carbonate, Gypsum, Clay	Angular to Subround	
22	Truck Cross Country Light Volcanic	73	Quartz, Feldspar	27	Clay, Mica	Angular to Round	Feldspar usually highly weathered, see Yuma rock sample R 22
23	Truck Cross Country Dark Volcanic	64	Quartz, Feldspar	36	Iron stained, grains, Clay, Mica	Subround to sub Angular	Badly iron stained grains feldspar usually highly weathered, see Yuma rock sample R 23

which is always drab, either dull green, gray, or brownish. The plants, whether shrubs or trees, are generally small, rigid, or woody, and have extensive but not especially deep root systems.

d. *Noxious Plants*

Thorniness is more likely to be encountered in the tree growths such as mesquite, ironwood, and cat's claw than in the shrubs. The only plant in the area that might be described as truly noxious is the cholla, a cactus that is found occasionally in all of the dry (sparse) types; the penetrating ability and microscopic barbs of its spines make it a plant to be avoided. The spiny or thorny plants, however, except in the case of mesquite thickets in some of the bottomlands, can be avoided with relative ease.

E. TEST COURSES AND TEST AREAS

1. General

Test courses located in the southwestern area of the Proving Ground are indicated in Figure III-24, superimposed on a representation of the types of surface materials on which the test courses and areas are situated. Test sites outside of the mapped area are included in the following list of test courses and areas:

a. *Truck Hill Course*

This is a 2.7-mile course located in the hills adjacent to the Mobility Complex, with grades up to 20 percent. Road surfaces vary from a rough, rock surface to loose rock, gravel, and sand. Operation on this course requires frequent braking and transmission shifting under load.

b. *Tank Hill Course "B"*

This 5.2-mile course is located in an area of rocky hills in the Laguna Mountains south of the other test courses. It includes short, steep slopes (35 percent maximum) plus slopes with less than 20 percent gradients. Driving surfaces vary from sand and gravel to exposed bedrock, including a large proportion of loose gravel with sharp stones and rocks.

c. *Test Slope Course*

Forward slopes of 5, 15, 20, 30, 40 and 60 percent grade are surfaced with gravel, asphalt or concrete. Vehicle gradeability, brake holding, and fuel and lubricating systems, functioning at various vehicle attitudes, are checked on these slopes. In addition, 10 to 40 percent compacted gravel side slopes provide means for checking vehicle stability on side slopes.

d. *Tank Gravel Course*

Located just south of the Mobility Complex headquarters, this 3.6-mile, graded and compacted gravel course consists of short, straight sections and curves of various radii, simulating secondary gravel roads. Operation of tracked vehicles and heavy trucks on it provide test of steering mechanisms at medium speeds.

e. *Tank Level Cross-Country Course*

Also just south of the Mobility Complex headquarters, a 6.7-mile course incorporates naturally the many ruts, bumps, and dust conditions typical of desert cross-country terrain. Vehicle suspension systems and overall durability are severely tested.

f. *Sandy Slope Course*

Graded sand slopes of 10, 15, 20, and 30 percent were prepared by bulldozing and are maintained in uniform condition by disc harrowing. Vehicle stability is observed on 10 to 40 percent side slopes. Surface material is loose, dry, wind-sorted sand.

FIGURE III 24. PARTIAL MAP OF TEST COURSES *g. Sand Dynamometer Course*

Vehicle speeds and tractive effort in sand are determined on this straight, level course of loose, dry sand.

h. Vapor Lock Course

Located in a dry wash, in which the soil is a loose, deep mixture of coarsely graded sand and gravel, this course consists of loops of 1, 3, and 7 miles in an area in which summer temperatures are generally the highest in the Proving Ground. Of use principally for gasoline-fueled vehicles, it is still used for diesel-powered vehicles.

i. Dust Course

Located 3 miles south of KOFA Range area where the soil is finely divided silt and sand, this 1-mile oval course is a site for vehicle and component tests under extremely dusty conditions.

j. Laguna Mountain Truck Hill Course

Located just south of the Tank Gravel Course, this 5.5 mile course traverses slopes of various degrees. The 20-ft roadway, surfaced with a natural soil, including various size rock and gravel, is used for testing components of wheeled vehicles.

k. Mobility Complex

Topographically, this area consists of flat terrain bordered to the north and west by low-lying hills. It is relatively close to the KOFA Range, Laguna Army Airfield Complex, Main Post, and numerous vehicle test courses.

l. Truck Level Cross-Country Course

Traversing typical desert terrain, consisting of desert pavement, sand and gravel, washes, and loose-sand areas, this course is located 0.6 miles west of Laguna Army Airfield Complex. Durability of wheeled vehicles is evaluated on its 6.4-mile length.

m. Laguna Army Airfield Complex

Located just north of the Mobility Complex area in the center of a large, flat valley with low-lying hills to the north, west, and south, it provides a suitable location for aircraft-related facilities and operations. Approach zones are considered unobstructed because of the absence of predominant land features within 1.5 miles of the main runway.

n. Phillips Drop Zone

A large, flat, sandy-surfaced area used for tests involving personnel airdrops.

o. Dynamometer Course (surfaced)

Located 1.5 miles northwest of KOFA Range Complex, near U.S. Highway 95, on very flat terrain, this course includes a 2.0-mile straight section, 30 ft wide with 500-ft radius turn-arounds at each end. Vehicle tractive capabilities on paved surfaces are determined utilizing a mobile field dynamometer, Figure III-25.

p. East Environmental Test Area

This is a long-term climatic storage area located on the plain north of the Muggins mountains.

q. West Environmental Test Area

Located on a broad plain bordering the southern portion of Cibola Firing Range and surrounded by gently rolling terrain, this area is used for static climatic testing.

r. Coyote Drop Zone

Also situated on the broad, gravelly plain just southeast of the West Environmental Test area, this area is used for cargo airdrop tests.

FIGURE III-25. TEST VEHICLE TOWING FIELD DYNAMOMETER DURING COOLING TEST ON PAVED DYNAMOMETER COURSE

s. *Roadrunner Drop Zone*

The third drop zone in this area, Roadrunner Drop Zone, lies generally east of Phillips and Coyote Zones. It is used for hazardous cargo airdrops and for tests of LAPES, Low Altitude Parachute Extraction System.

t. *Gravel Course*

This is approximately 3 miles of abandoned highway (no pavement) located on relatively flat gravelly terrain.

u. *KOFA Range Complex*

Only a portion of the KOFA Complex is indicated on Figure III-24. Range facilities are located just to the west of the Firing Front. The range proper extends almost due east for 40.4 miles and is 5.6 miles wide. Range facilities are situated on flat terrain and house functions related to tube artillery and weapons testing and test data acquisition. KOFA Firing Range traverses the relatively flat, gravelly, Castle Dome Plain and King Valley, with Castle Dome Mountains intruding partially from the north down range from the Firing Front. It is the focal point of tube artillery at YPG.

v. *Rocket Alley*

This is a ground-based 2.75 in. rocket test area. It is 76.5 by 0.6 km and has three marked impact areas.

w. *Truck Gravel Course*

An elongated loop just east of U.S. Highway 95, about midway between Castle Dome Heliport and the northern end of KOFA Firing Front, on the flat, gravelly Castle Dome Plain, the course is 3.1 miles long and 40 ft wide. With a graded gravel surface for vehicle operation, it simulates operations on secondary roads at convoy speeds.

x. *Castle Dome Heliport*

Located on the broad, flat, gravelly, Castle Dome Plain, continuous north and south, the heliport has rugged mountains to the east and west. It is used as a staging and maintenance area for aircraft and aircraft armament testing.

y. *Castle Dome Heliport Annex Graze Firing Range*

This area is in the foothills of the Middle Mountains, northwest of Castle Dome Heliport and west of U.S. Highway 95. In addition to test support facilities, it contains a combination 3000m target range and graze range for ground-to-ground developmental tests of aircraft armament and components. The Large MultiPurpose Environmental Chamber (LMPEC) is located here. This chamber can temperature condition large complete systems. Weapons can be functioned by firing through ports.

r. Moving Target Range

This range has a 1-mile straightaway and loops at each end. The rail and target carrier are protected by earth berms.

2. **Other Areas**

Outside the area mapped in Figure III-24, or otherwise not indicated, are the following:.

a. Cibola Range Complex

Comprising all of the western arm of the Proving Ground north of the West Environmental Test Area, the complex is approximately 40 miles north-to-south and 18 miles east-to-west. Mountain barriers surround the central portion, making it ideal for aircraft armament testing. Rocket Alley and the Moving Target Range are both in the Cibola Range Complex.

b. Pyrotechnic Firing Range

Located at the extreme eastern end of KOFA Firing Range, this range is used for dynamic testing of tactical luminants.

c. Rock Ledge Course

Approximately 28 miles north of the Mobility Complex, this course lies adjacent to U.S. Highway 95 and is used for testing vehicle suspension systems and components.

d. Paved Courses

U.S. Highway 95, which traverses the Proving Ground for 50 miles, and a level, 5-mile paved course adjacent to it, are available for endurance and engineering tests of wheeled and light, tracked vehicles.

e. Obstacle and Slope Courses

Located throughout the Mobility Complex area are six courses, three obstacle courses consisting of a vertical wall, bridging device, and a simulated shell hole and three slope courses with vertical slopes, side slopes, and sand slopes.

f. Vehicle Turning Circle

This course is used to measure vehicle turning radii and to evaluate fields of vision and fields of fire.

g. Bore Sight Range

This is a 1500-yard range for aligning and checking sighting systems on targets at 500, 1000, and 1500 yards from the sighting position.

h. Water Spray Facility

Located in the Mobility Complex, this facility is employed to determine the effectiveness of vehicle water seals.

i. Water Test Facilities

(1) Clear Lake

A shallow lake formed by a natural diversion of the Colorado River, where Yuma Wash meets the River Valley, is sometimes used for shallow fording tests.

(2) Mittry Lake

A marshy area downstream of Laguna Dam on the Arizona side of the river includes a marshy area useful for testing engineer fording and bridging equipment.

(3) Senator Wash Reservoir

Formed on the California side, upstream from Imperial Dam, this reservoir is basically for irrigation water impoundment. Because of its depth and summer time high temperature, it may be used for testing amphibious vehicles to meet requirements of operation in high-temperature waters.

3. Airspace

Because of the artillery and aircraft armament testing at YPG, certain airspace restrictions are necessary. Figure III-26 depicts the various airspace envelopes, their designations and proportions. Restricted Airspace R-2307, surface to unlimited ceiling, covers the artillery firing range portion of the KOFA Firing Range. R2308 "B", surface to 80,000 feet, covers the extreme northeast leg of the installation. R2308 "A" 1,500 to 80,000 feet, covers all of the Cibola Firing Range, with the exception of a small strip about 1 mile wide and 10 miles long north and south along the western boundary just north of R2307. R2306 "C", surface to 17,000 feet, covers a small portion of the northwest Cibola Firing Range. Yuma Proving Ground controls the use of R-2306 A, B and C; R-2307; and R-2308 A and B airspaces exclusively. These areas are released to the Federal Aviation Agency when there is no DOD requirement, which occurs on a daily basis, normally in the evening hours and on weekends. During these periods, commercial aircraft regularly overfly the Proving Ground. The Marine Corps Air Station (MCAS) Yuma makes extensive use of R-2306 and R-2308 above 10,000 feet for tactical training maneuvers.

F. COMPARISON OF YPG WITH OTHER WORLD DESERT AREAS

1. General

In Table II-2, environmental characteristics of YPG and other world deserts are tabulated, allowing the reader to make independent comparisons depending on his specific interests and upon available data. For further detail, the serious user of this publication is urged to use the Yuma Climatic Analogs[56-65] prepared by the Quartermaster Research and Engineering Center and the Terrain Analogs prepared by Waterways Station, Corps of Engineers.[?] These works are immensely valuable in the extent of data compiled and analyzed.

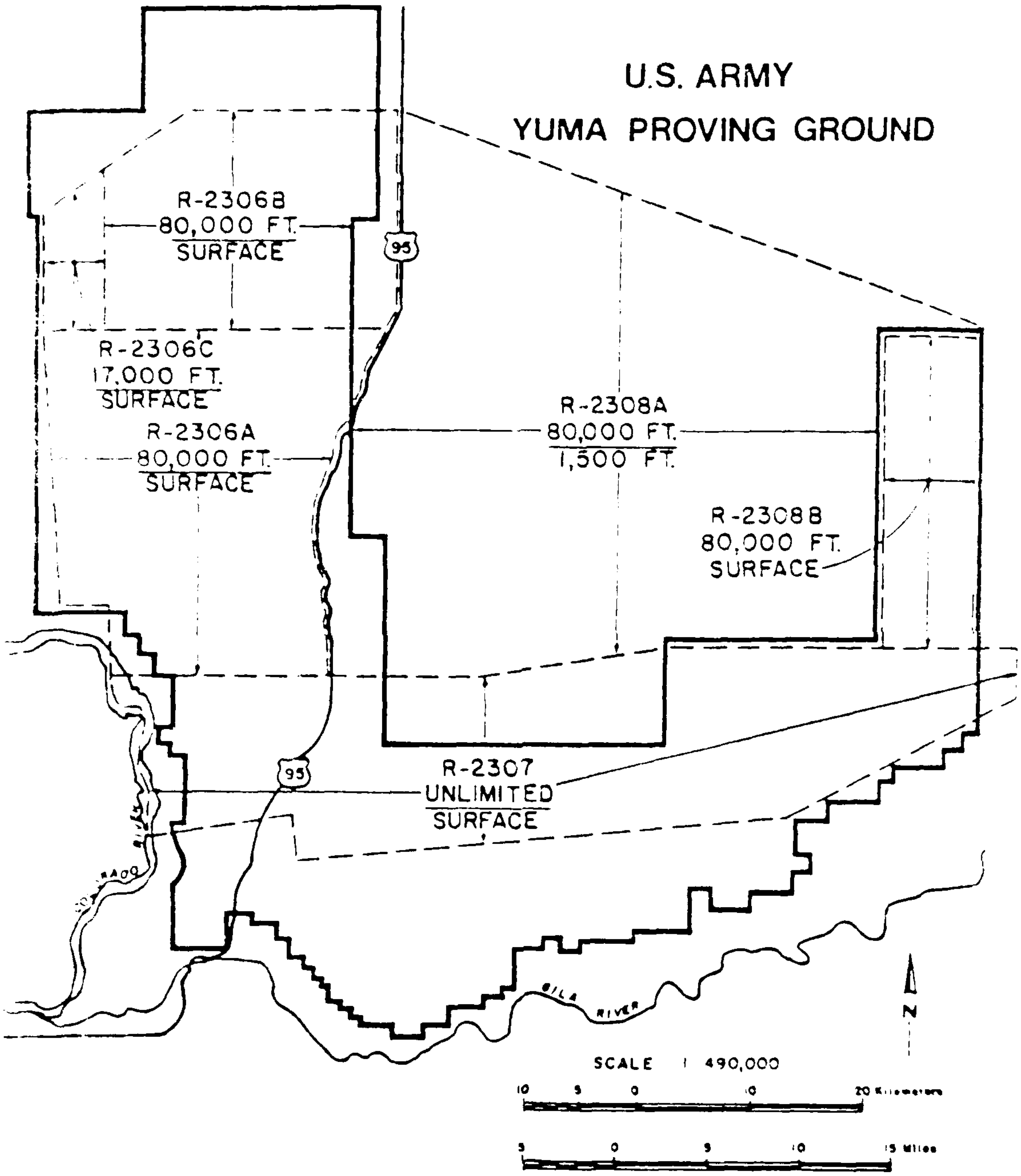


FIGURE III-26. RESTRICTED AIR SPACE ENVELOPES

a. *Climate*

In using these analogs one must recognize the significance of scale. YPG proper covers an area roughly 53 miles by 64 miles. A majority of the meteorological data by which it is characterized is recorded at a single station in the Mobility Test Complex. Admitting possibilities of variations in meteorological factors because of the extent and terrain topography of the Proving Ground, it is safe to say that the data of record are representative of the Proving Ground generally. In comparison, the smallest area covered by a climatic analog is that of East Central Africa, about 700 miles by 1000 miles, with a maximum distance of about 350 miles between weather stations. The greatest extent of coverage is the analog for South America, about 3200 miles by 4530 miles, the two most distant weather stations 260 miles apart.

In general, the degree of analogy is indicated for each desert area in terms of "closely analogous" if temperatures are within 5 F above or below the corresponding level for Yuma, "semianalogous" if within 10 F above or below; rainfall between 2 and 6 inches closely analogous, and between 6 and 9 inches semianalogous. Wind speeds between 4 and 7 mph are closely analogous and less than 4 or from 8 to 12 mph semianalogous. By graphic representation, areas of the two degrees of analogy with Yuma are indicated. Available analogs of the Yuma climate are excerpted in following paragraphs. A degree of interpretation must be exercised because it is the intent of this publication to indicate which areas of YPG are analogous to other world deserts. The analogs indicate the areas of other world deserts analogous to YPG.

(1) Middle East[66]

"The climate of the Middle East has strong resemblance to that of Yuma, Arizona. The similarity is particularly close in all important respects, both winter and summer, in the valley of the Jordan River in Israel and Jordan and in the southern part of the Mesopotamian lowland between Baghdad and Basra. Although these areas of close analogy are of small extent, areas in which single elements of the climate, such as winter temperatures, summer temperatures, and annual precipitation, are analogous include very considerable parts of the Middle East. When areas that may be considered semianalogous are added to these, certain climatic elements are found to be more or less comparable to Yuma over most of the Middle East region. This is especially true of precipitation, as only the Mediterranean coast and the highlands around the margins of the region have a mean annual precipitation in excess of the amount adopted here as the limit of semianalogy. The yearly distribution of precipitation, however, is roughly comparable to that of Yuma only on the south coast of Arabia, where rain is received in both summer and winter. Average and extreme values for summer and winter temperatures are closely analogous to those at Yuma over considerable areas, although these seasonally analogous zones overlap only in interior Arabia, southern Iraq, and the Dead Sea Rift Valley. Of the climatic elements considered here, the July mean dew point temperature has the most restricted area of analogy; such areas were found to exist only in a relatively narrow band near the coasts and in the Syrian plateau, in addition to the two areas of complete analogy."

(2) Northeast Africa[67]

"Northeast Africa has considerable areas where the important climatic elements are closely analogous to those at Yuma, although there are few, if any, places where these all coincide. Temperatures of the coldest month are analogous over about the northern two-thirds of the region, reaching the Mediterranean coast in most places. Areas where temperatures of the warmest month are analogous do not lie so far north but extend southward beyond the southern limits of aridity, merging into the perennially hot, tropical regions. In the interior, only the higher elevations of the Tibesti Mountains and the highlands of Ennedi [illegible] included [illegible] Analogous [illegible] dew points plotted [illegible] mean annual [illegible] dew point [illegible] confined to two transverse bands [illegible] width, one in the north paralleling the Mediterranean coast and one in the south in the transitional [illegible] desert [illegible] to tropical steppe. Areas of analogous dew points are also found in a narrow [illegible] along the Red Sea coast. The vast interior of Northeast Africa is practically rainless and [illegible] Yuma, where [illegible]

[illegible] precipitation [illegible] Yuma [illegible] wet and dry seasons [illegible] the Red Sea coast near Port Sudan [illegible]

(3) Northwest Africa[illegible]

[illegible] of Northwest Africa in which temperatures are [illegible] winter [illegible] are limited [illegible] the interior side of the Atlas Mountains [illegible] Ahaggar Mountains and [illegible] the large area of composite [illegible] parts of the [illegible] area are not analogous in either summer or winter because [illegible] the Atlas ranges and the Ahaggar [illegible] Atlas Mountains [illegible] the 32nd parallel [illegible] too cool to be analogous [illegible] temperatures are analogous in summer [illegible] are less extensive than in Northeast Africa. When areas of analogous mean annual precipitation [illegible] transverse bands are superimposed on the map of composite temperature analogy [illegible] are found along the desert piedmont of the Atlas Mountains, including a large section [illegible] of the Gulf of Gabes and farther south in the [illegible] Highlands. The vast, nearly rainless interior of the [illegible] than Yuma everywhere except in a few elevated places. Rainfall is quite different from Yuma [illegible] winter maximum in the north and summer maximum in the [illegible] of both summer and winter maximum at Yuma. Conditions of dew point [illegible] Yuma [illegible] in transverse bands in Northwest Africa [illegible] The interior Sahara is less humid and even more sunny [illegible] Yuma [illegible] better than at Yuma, although sandstorms are [illegible] temperature range in the warmest month shows the [illegible] Yuma [illegible] of Northwest Africa exclusive of the immediate

(4) South Central Asia[illegible]

[illegible] areas of South Central Asia have summer temperatures analogous to those [illegible] the extremely hot Indus Valley of Pakistan and the interior basins of Iran, and in the [illegible] of Kashmir, Afghanistan, and northern Iran are summer temperature regimes ap[illegible] different from those at Yuma. In winter, however, the area of temperature analogy is restricted by [illegible] of temperatures higher than at Yuma in the southern part of the Indian lowlands and by the [illegible] of lower temperatures in the elevated interior of Iran. Mean annual precipitation falls within some [illegible] of analogy (less than 9 inches) over most of the study area. The only areas with higher rainfall are the lowland portion of India subject to monsoon rains, the northwestern part of Iran bordering the Caspian Sea, and some of the higher mountains. The combined areas of analogy and semianalogy for mean July cloudiness are approximately the same as for mean annual precipitation. Mean July wind speeds are likewise analogous or semianalogous at most of the stations for which values are available, being too high only at some of the coastal stations and in the vicinity of the Seistan Basin near the center of the region. Summer dew points are analogous in a comparatively narrow band between the humid regions that are subject to maritime influence and the dry highland regions of Kashmir, Afghanistan, and Iran. This analogous band is widest in western Baluchistan and swings northwest near the Persian Gulf coast to the northwestern border of Iran. The greatest coincidence of analogy of combined climatic elements is in the western Baluchistan, as shown by the records of Panjgur; a similar area of nearly total analogy is found in the Indus River Valley of West Pakistan in the vicinity of Bahawalpur."

(5) *Soviet Middle Asia*

"All of Soviet Middle Asia is north of the latitude of Yuma, and most of it is, therefore, too cool for temperature analogy with Yuma. In the extreme south, however, two areas have summer temperatures high enough to be analogous. Winters are much colder than at Yuma. Mean annual precipitation is analogous (2 to 6 inches) over a large area extending from the Caspian Sea to the foot of the Tien Shan. Approximately the same area is analogous or semianalogous to Yuma in respect to mean July cloud cover, with less than three-tenths of sky cover. Mean July wind speeds are analogous or semianalogous (less than 12 mph) at all stations for which data are available except Baku on the Caspian coast, where a mean of 14 mph is recorded. Summer dew points are analogous in the southwestern portion of the study area, including the Aral Sea and the Caspian Sea regions. The greatest coincidence of analogy of combined climatic elements is in the extreme southern portion of the study area. Termez on the Afghanistan border is climatically most similar to Yuma; only the occurrence of lower winter temperatures at Termez prevents analogy of all climatic elements investigated."

(6) *Chinese Inner Asia*

"No part of Chinese Inner Asia is climatically analogous to Yuma in both winter and summer. Winters are far too cold everywhere to be considered analogous, and summers are too cool in most places, but in summer one small area - the Turfan Depression in Sinkiang - is much like Yuma in respect to temperature and precipitation. Considering only mean temperature for the warmest month, for which the Yuma value is 91°F, the area of comparability (within 5°F) also includes the valley of the Wei Ho in Shensi province. A large portion of the study area has mean annual precipitation between 2 and 6 inches and is therefore considered analogous to the Yuma mean of 3.4 inches. Much of the Tarim Basin has a mean of less than 2 inches and is thus semianalogous to Yuma. The entire area has mean cloudiness greater than 3.0 in July, too high to be analogous to the Yuma average 0.16. Mean July wind speeds are analogous to semianalogous (less than 12 mph) at all stations for which data are available. Most of Chinese Inner Asia has lower dew points than Yuma; only in the more humid southeast are dew points of the same order as, or higher than, the August value of 64°F at Yuma.

(7) *East Central Africa*

"In East Central Africa, climatic analogies with Yuma for most elements are restricted to relatively small areas. Temperatures during the warmest month are analogous along the narrow coastal strip that borders the Red Sea and the Gulf of Aden and in sections of interior Somalia and Kenya. The interior highlands are too cool for analogy during the warmest month but in the coldest month have analogous temperatures at elevations above approximately 6000 feet. Owing to of the greater annual range at Yuma, there is no overlap in East Central Africa between areas of temperature analogy for the warmest and coldest months. Areas of analogy in mean annual precipitation (2 to 6 inches) coincide largely with the coastal area of warmest month analogy and occur in the interior only in an isolated pocket adjacent to Lake Rudolf. Mean annual rainfall of 2 to 6 inches (semiarid [illegible]) [illegible] in two narrow coastal areas of Eritrea and British Somaliland [illegible] the interior highland [illegible] rainfall is [illegible]. Mean [illegible] are considerably higher in the coastal areas than at [illegible] and [illegible] at the intermediate elevations of the interior. Mean [illegible] adjacent to the Red Sea coast of [illegible] Africa and [illegible] northern [illegible] Somalia [illegible] analogous at both [illegible] stations in Eritrea and at several stations along the Ethiopian-Sudanese border; elsewhere, wind data are largely lacking. Within East Central Africa there is no complete all-year analogy to Yuma climate. However, [illegible] of North Africa [illegible] Yuma [illegible] respects and [illegible] [illegible]."

[illegible] Southern Africa [illegible]

Nowhere in southern Africa [illegible] the overall character of the climate be considered closely analogous to that at Yuma. Warmest month temperature analogy occurs only in a small section of the [illegible] and upper Zambezi Valley and not at all in the elevated Kalahari Basin or the coastal stretches of the Namib, the two principal deserts of the study region. In both deserts, summer temperatures are too low for analogy, for reasons associated with 3000 and more feet of elevation in the case of the Kalahari and for reasons of exposure to cooling maritime influences in the case of the Namib. Coldest month temperature analogy, on the other hand, is widespread throughout the interior and western districts of southern Africa and includes both the coastal and plateau deserts. With respect to mean annual precipitation, a narrow zone of analogy in the uplands bordering the interior plateau on the west separates the drier than Yuma western coastal lowlands from the wetter than Yuma plateau and eastern coastal lowlands. Combined analogy for the three principal elements (mean annual precipitation and mean temperatures for the warmest and coldest months) is not evident within the study region, and dual analogy occurs only between mean temperature for the coldest month and mean annual precipitation in the uplands to the west of the interior plateau. With respect to elements of secondary importance to overall climatic analogy, considerable similarity between Yuma and southern Africa was found for mean summer wind speed and mean daily temperature range, warmest month. As for cloud cover, the few available observations on cloud amounts indicate that southern Africa is generally too cloudy during the warmest month for analogy with Yuma."

[illegible] South America [illegible]

"No area of close analogy to Yuma climate is found in South America. However, when single elements of climate are considered, such as mean temperature for the coldest month or mean annual precipitation, some areas are closely analogous. When areas of semianalogy are added, certain climatic elements are found to be comparable to Yuma over much of the continent.

Warmest month temperature analogy occurs in northern Argentina, western Paraguay, and eastern Bolivia. Coldest month temperature analogy is found on the northern coast of Chile, the Andean foothills of western Peru, and the highlands of Ecuador, Colombia, and Venezuela. On the eastern side of the Andes, more areas of analogy are found in Bolivia, Uruguay, southern Brazil, and the lowlands of northern Argentina. Mean daily maximum temperature analogy is confined to a small area of northern Argentina. Much of northern Argentina, southern Brazil, Uruguay, and various areas of the Andes, are anal ogous for mean daily temperatures during the coldest month. Analogous mean daily temperature ranges are found throughout most of Argentina, Uruguay, and Paraguay, and at various elevations in the Andes and the upland regions of the northern countries in the study area. A small area of absolute maximum temperature analogy exists in northern Argentina. A narrow strip of precipitation analogy is found in Peru and extends southward to central Chile between the drier coastal lowlands and the wetter uplands, as well as in northwestern Argentina. Warmest-month cloudiness analogy is found in the western foothills of the Andes between 22° and 37° South latitude. Analogous areas of wind speed are found over most of the study area. There are no regions of mean dew point analogy for the warmest month or mean relative humidity for the driest month in South America."

(10) Australia[65]

"The climate in much of Australia is analogous to that at Yuma in one or more elements, especially mean monthly temperature. The non-analogous areas are the higher mountain areas and the east coastal lowlands. The continent is much more comparable to Yuma in winter than in summer. Most of the continent receives too much precipitation for close analogy of more than two elements, except in the Lake Eyre basin. Even here, the analogous delimitation is based on extrapolated values rather than on station data within the region. Even the driest station in Australia receives more rain than Yuma. Mean relative humidities, however, in more than half the continent are analogous to those at Yuma. The absolute maximum temperature, 127°F, at Cloncurry comes within one degree of being too high for analogy. A general paucity of interior stations prevents a thorough analysis of Australian climates, and any climatic analog study must be considered provisional."

b. Terrain

(1) General

The effect of scale is also significant in applying the terrain analogs, and in evaluating their usefulness, possibly more so than with respect to the climatic analogs. Whereas climatic factors at Yuma are relatively homogeneous from area to area and within usual working heights above ground surface, considerable variations may exist in terrain characteristics at ground surface and below within those same area differentials. In addition, the relative significance of terrain characteristics depends heavily on the intended terrain use, such as movement of material or personnel over it, excavation, construction, camouflage, concealment, projectile impact, seismic shock, etc. Granting the importance of those variables, estimating the comparability of YPG and other desert areas is heavily dependent on the accuracy with which terrain characteristics of each are represented. Qualitative methods consist of written descriptions and photographs or other pictorial representations, which depend on skill in word usage, photography, artistry, etc., causing such methods to be subjective and difficult to use for comparison purposes.

The terrain analogs[22] adopt a quantitative approach in which the following terrain characteristics are represented numerically (see also Para. II.A.5 of this report):

- Characteristic slope
- Characteristic relief
- Occurrence of slopes greater than 50 percent
- Characteristic plan-profile
- Soil type
- Soil consistency
- Surface rock
- Vegetation
- Generalized landscape

By assignment of numerical values to various degrees or compositions of each characteristic on a mapped area, a numerical representation is achieved for the ground area mapped. The degree of analogy between two areas, such as YPG and a world desert area, is thus represented by comparison of numerical descriptors. Figure III-27 is such a representation for YPG plan-profile, Figure III-28 a representation for general landscape, and Figure III-29 a representation for soil consistency. With the same treatment accorded some other desert area, the degree of analogy for these specific features is ascertainable by numerical comparison. In Figure III-30, a Geometry Analog or Landform Analog (comprising appropriate analyses of such as Figures III-27 and 28) indicates the degree of analogy between specific areas of YPG and the northwest African Desert (not shown). For example, with the analogs for both areas available, it can be seen that King Valley is analogous to a large area in northwest Niger, and portions of the Tank Mountains, Palomas Mountains, Castle Dome Mountains, Muggins Mountains, and Chocolate Mountains are analogous to an extensive area in Algeria north, northwest, and northeast of Fort Laperinne. Similarly, with appropriate terrain analogs at hand, areas of YPG terrain, analogous or not analogous to other world deserts, could be ascertained. To date, there appear to be two obstacles to use of the terrain analogs for materiel testing and test planning, both bearing on accuracy. Some of the terrain factor maps, such as Characteristic Plan-Profile, are based on random sampling of areas within a 1 mile diameter circle, in which differences in surface elevation of less than 10 ft are not considered. Another obstacle is that of describing the boundaries of an area of interest with sufficient accuracy that it can be located precisely on a plane map. Depending on the type of material to be tested, a change in ground elevation of 10 ft or the profile of a wash may present test conditions not truly representative of the performance requirements of the item. The obstacle of accurately describing and delineating on a map the ground location of a specific ground area has to do with problems of cartography and map reproduction, modification, and interpretation. As examples, the YPG areas of terrain characterized on each plate of the terrain analogs cover an area of one degree of longitude and one-half degree of latitude, a major part but not all of YPG. Indices for reference are the lines of longitude, 114° 00′ and latitude, 33° 00′, with ties indicating 15′ intervals along the 33° 00′ line. The Proving Ground boundaries are not shown. The scale of the printed area is approximately 1:400,000. Identification of a salient mapped feature on the Proving Ground surface is, thus, subject to distortions inherent in reproduction processes, magnified by the map scale.

2. Conclusions

Conclusions in the various terrain analogs take such forms as the following.

In general terms, the terrain of the Northwest African desert is moderately analogous to that at Yuma Proving Ground. Approximately 22 percent of the study area is highly analogous, 41 percent is moderately analogous, 35 percent is slightly analogous, and 3 percent is inappreciably analogous to terrain types found at Yuma. Two areas of the Tagant Plateau in the extreme southern part of Mauritania, occupying less than 1 percent of the study area, fall within the not-analogous category.

Highly analogous areas are found within all of the physiographic units of NWA except the plateau regions. Mountainous regions mapped as highly analogous include the Ahaggar, the eastern part of the Air, and the Anti Atlas.

The eastern half of the Grand Erg Oriental, the Erg Chech, the dunes and hill lands of Spanish Sahara, and numerous desert plain areas scattered throughout the study area were included in the highly analogous category.

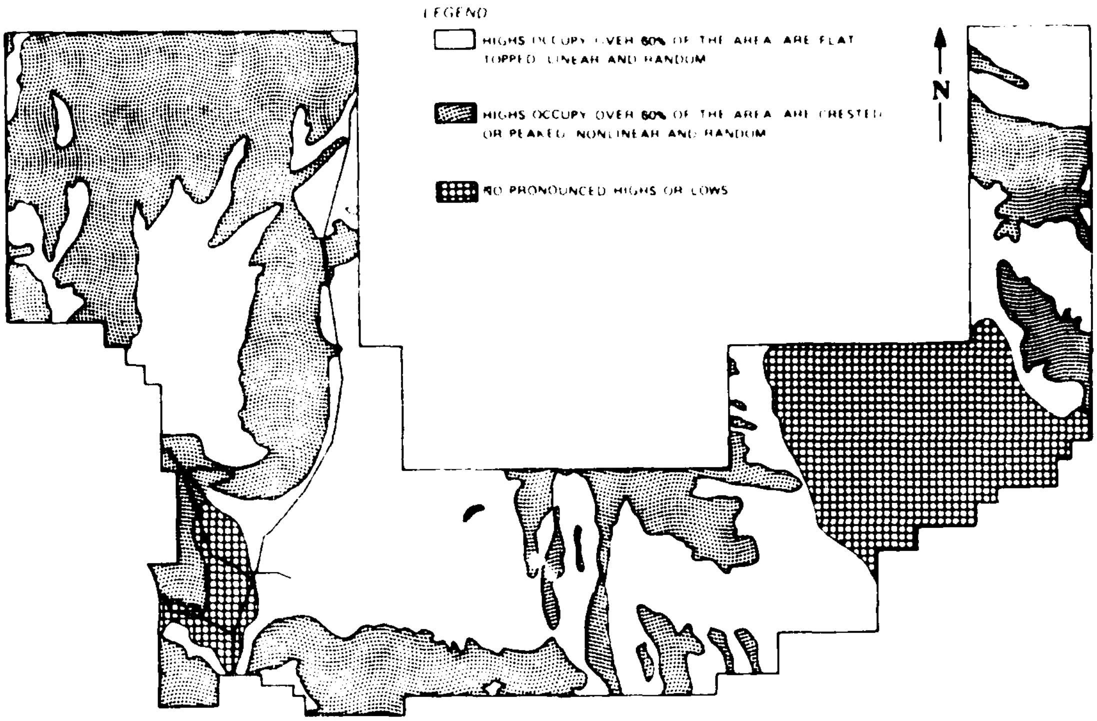


FIGURE III-27. U.S. ARMY YUMA PROVING GROUND (PARTIAL) CHARACTERISTIC *PLAN-PROFILE*

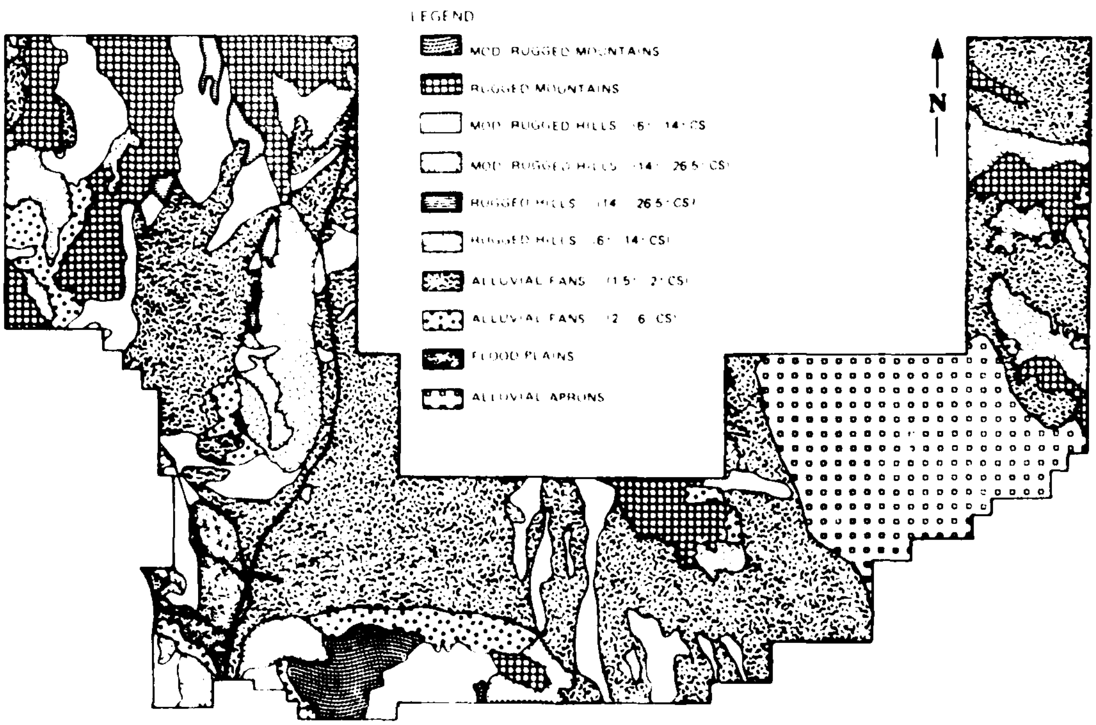


FIGURE III-28. U.S. ARMY YUMA PROVING GROUND (PARTIAL) GENERALIZED LANDSCAPE

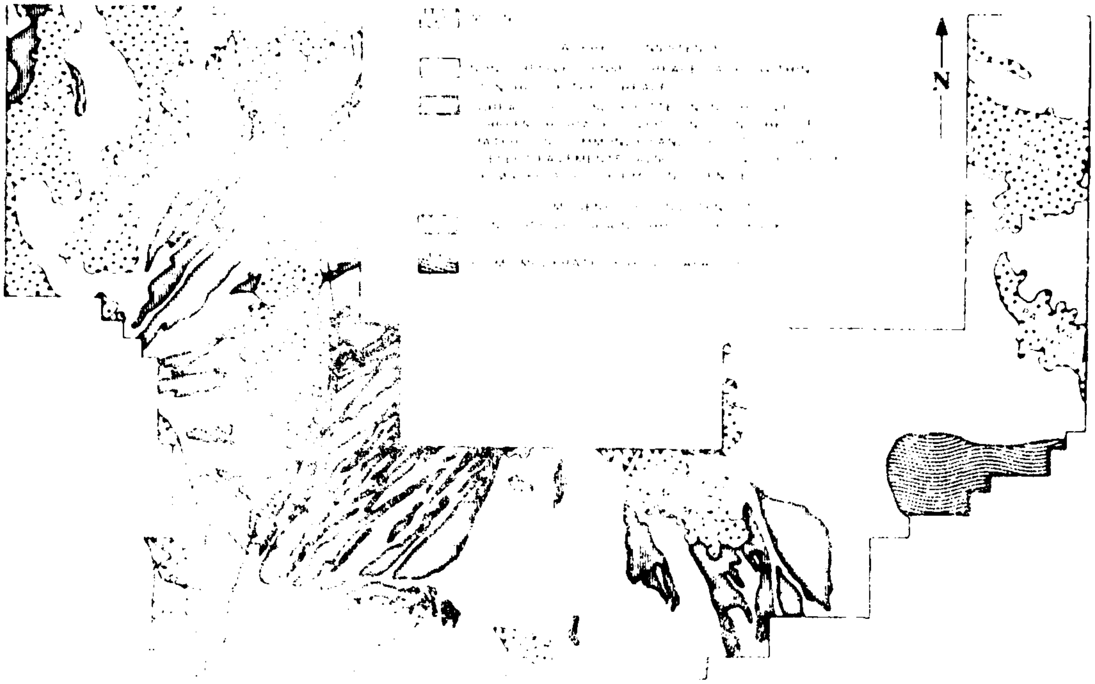


FIGURE ... PROVING GROUND (PARTIAL) SOIL CONSISTENCY

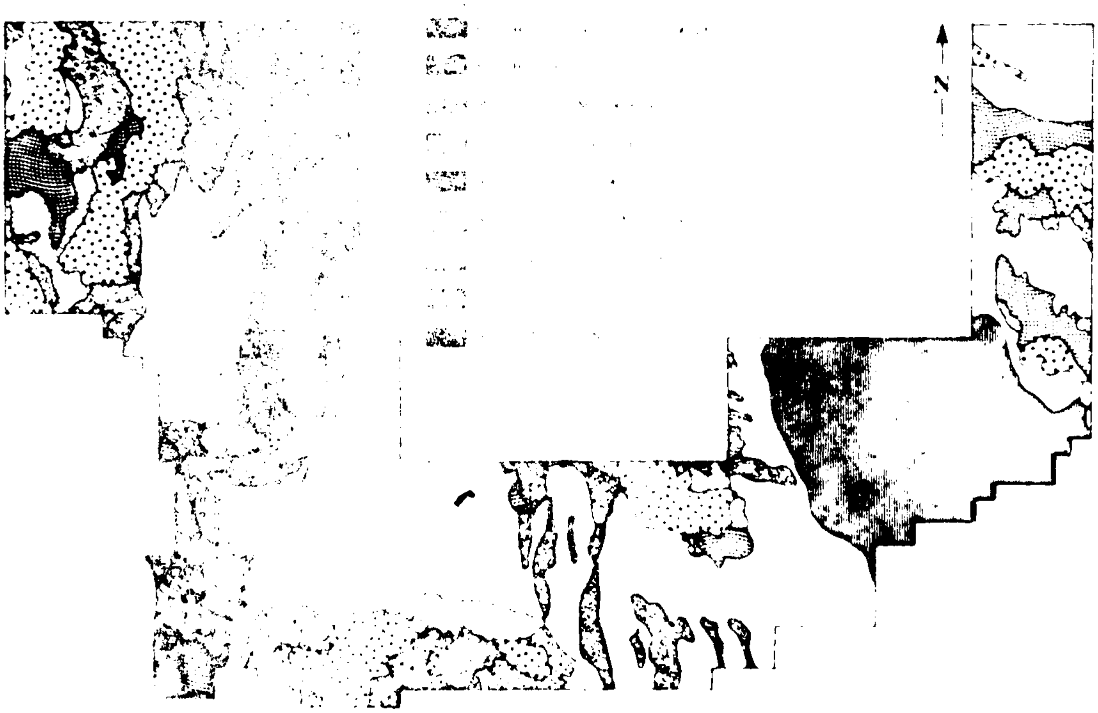


FIGURE III ... YUMA PROVING GROUND (PARTIAL) GEOMETRY ANALOGS

Plains comprise the majority of the physiographic types within the moderately analogous category. These plains include the Tanezrouft, Aouker Basin, El Djouf, Admer, Northern Tenere, the depression plains of Algeria and Mauritania, the flood plain of the Niger River, and the Tunisian coastal plain. The High Atlas, Saharien Atlas, and the western Air Mountains proved to be moderately analogous to their Yuma counterpart. The hill lands of Adrar des Iforas and the dunes of Irrarene, Makteir, and the Grand Erg Occidental were also mapped as moderately analogous.

Included in the slightly analogous category are the plateau regions of El Hank, Tademait, the Southern Tassili, and the Hamada du Guir; the clay plains of Southeastern Niger, the Southern Tenere and numerous other plain areas throughout the study area; and the dune areas of Southwestern Mauritania.

Inappreciably analogous areas are confined chiefly to the Algerian High Plateau, the Tassili-n-Ajjer, the Spanish Sahara plateaus, the Hamada de Tinghert, and the Plateau of Irhaquriten.

At the expense of repetition, these documents develop analogs of foreign desert areas with YPG (inherent in the analog design), whereas it is the intent of this document to show areas of YPG that are analogous to other desert areas. The generalities of a summary of such detail as contained in the terrain analogs do not compare specific areas of foreign deserts with specific areas of YPG. To elaborate in detail necessary to do so, although very useful, might result in an overly cumbersome document.

IV. MATERIEL TESTING REQUIREMENT

A. GENERAL TESTING REQUIREMENTS

The varied materiel systems of the Army are obviously differently influenced by the adverse elements of the desert environment, and the individual components of those systems are, perhaps, even more varied in their responses. It must be recognized that for purposes of effective and efficient control of the processes of performance evaluation, specific types of materiel should be tested in facilities designed to maximize such control. In general, this means that even when operated in the natural environment, each type of materiel item — weapon, vehicle, aircraft, ammunition, instrumentation shelter — would ideally have a test facility specifically selected and designed to analyze its performance in an efficient, thorough manner.

Such an approach envisions ranges for testing artillery, missiles, automatic weapons, and small arms; flat, hilly and cross country, as well as highway driving courses for vehicles; paved and unpaved landing strips and pads for aircraft and missile delivery systems; impact areas for artillery, rockets and missiles; fixed and moving target ranges for tank weapons; and storage areas for various types of materials and supplies. Each test area would be equipped with the necessary instrumentation and test operation controls to obtain all of the pertinent data for proper evaluation of the materiel under examination.

It should be noted that the facilities required for desert environmental testing are, as a whole, not appreciably different from those required to test the same materiel in nonadverse environments. For much of the year, in fact, the natural desert environment is not adverse in comparison with other temperate areas, except perhaps for dust and aridity. These facilities can be used, therefore, as adjuncts or alternative testing facilities for those normally used for nonenvironmental testing missions. The major portion of the ongoing activity of Yuma Proving Ground is, in fact, not strictly environmental testing.

Insofar as this document is concerned, the discussion of requirements for facilities relates to the mission of evaluating adverse desert environment effects. That such testing is, in certain aspects, limited to the June-September period is not pertinent.

B. SCOPE OF DESERT TESTING

In testing military materiel for its suitability, all aspects of its life cycle to ultimate consumption or disposal must be considered. The several stages of the life cycle sequence, as presented in the *Introduction*, form the basis for the test plan developed for each type of equipment.

In addition to the three elements of the life cycle of transportation, storage, and use of equipment, which must be evaluated by testing, four other areas of concern are of major interest in determining their suitability. These are the criteria of security, safety, maintainability, and human factor acceptability, with particular regard to the influences of the desert.

During the active phases of tests established to obtain data of life cycle performance, these latter factors are under continuous, concurrent scrutiny. Specific comment sheets, check lists, and operator surveys are developed and completed concerning the acceptability of the equipment in these areas for its mission role.*

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*Although the primary concern is to assess the performance of the equipment in the desert, information of deficiencies that might appear under any other condition of operation must be noted as well.

"Security" is concerned with the degree to which the item reveals itself to enemy observation (raised dust during travel or operation, electromagnetic signal propagation, IR radiation from hot surfaces) and capability of masking its presence by camouflage techniques in the desert.

"Safety" relates to personnel in and adjacent to the materiel while operating, servicing, maintaining, handling, and storing it. Are they endangered by working with or being around the equipment? Does this environment affect the equipment to increase the hazards of its storage, transportation, or use, including servicing and maintenance?

"Maintainability analysis" requires a review of the relative capability of operator and service personnel performing the necessary adjustments, lubrication, and servicing required for proper operation of the equipment. Can adjustments be made without contacting excessively hot surfaces? Can lubrication be made without contacting excessively hot surfaces? Can lubrication be performed without danger of dirt or dust contamination? Do adjustments or servicing require special tools, removal of access panels, or exceptional dexterity to accomplish satisfactorily?

"Human factor" suitability is that aspect of the design of the equipment that relates to its impact on those associated with its operation. It may involve such elements as location of controls for efficient operation or maximum dexterity, ventilation for provision of clean, temperature controlled air; comfortable, shock resistant seating, cushioned eye pieces on viewing devices, protective, optical filters for viewing devices, and mechanical assist control for high load control systems and protection from exhaust gases, hot surfaces, electrical contacts, or other hazardous effects generated by the system. This would also include effects to personnel nearby who would not necessarily be directly involved in operation or servicing of the equipment.

In broad terms, these tests will include evaluation of the response of the subject item or system to the effects of the adverse environment under conditions of transportation to and within the operational zone (forward depot and field storage), field maintenance, and operational employment. Weapons will be driven, towed or carried to points of emplacement, left in the open, maintained, serviced and fired; ammunition will be transported, stored in containers, and uncased in the open and fired; vehicles will be driven on highways and cross country, maintained and serviced in the field; electronic equipment, aircraft and construction equipment, general equipment, and supplies will similarly be transported, stored, maintained, serviced and operated, and their responses measured and assessed for suitability in each aspect of the representative life cycle for each.

C TEST FACILITIES

The principal facilities required include firing ranges, driving courses, and storage and exposure sites, together with all of the supporting elements of supply, service, maintenance and technical, engineering, instrumentation and communication required.

1 Ranges

Firing and non-firing ranges to accommodate a wide variety of weapons and sighting, gun pointing and laying and tracking systems demand the largest portion of the area requirements of the test facility. Such ranges include, depending on the type of weapon, some or all of the following:

a Firing positions, with necessary instrumentation for measuring interior and exterior ballistic phenomena, ammunition storage and preparation areas, weapon inspection service and maintenance facilities, and personnel safety and working accommodations.

b. Firing ranges of adequate length for the weapons to be tested, with safe vertical airspace and width and with adequate impact areas and targets, as required. Ranges for tank guns and air-to-ground missiles require both fixed and moving target ranges having necessarily increased impact dispersion limits. Areas used for emplacement of mines under precisely controlled conditions should also be considered as range facilities.

c. Non-firing ranges or target arrays for determining performance and accuracy of sighting and ranging systems, gun-pointing systems, and missile guidance and control systems.

d. Transportation of weapons and munitions includes travel over varied terrain, simulating communication zone to forward depot, forward depot to forward supply point, and tactical transportation to point of emplacement or use. Typically, such travel might include paved and secondary roads and cross-country courses in sandy, gravelly, and rocky desert terrain on such a schedule as:[79]

To Forward Depot	50-mi paved, 150-mi secondary road
To Forward Supply Point	35-mi secondary road
Tactical Movement	70-mi sandy desert, cross-country
	30-mi gravelly desert, cross-country
	75-mi rocky desert, cross-country

Tactical deployment might be more specifically divided, as indicated in Table IV-1, into types of cross-country terrain, with regard to the types of weapon systems involved, for more realistic simulation.[79]

TABLE IV-1. GROUP CLASSIFICATION OF ARMAMENT AND INDIVIDUAL WEAPONS

Desert Terrain Component	Individual Small Arms (Not Crew Served)	Light and Medium Weight Crew Served Weapons**		Towed Weapons	Self Propelled Weapons
		Hand Carried	Vehicle Carried		
Secondary Roads*	10	10	50	70	20
Mountains	8	8	12	21	22
Badlands/Hills	3	3	5	8	9
Fans/Washes	8	8	11	19	20
Plains/Flats	19	19	27	47	49
Dunes Fields	7	7	10	20	20
Dust	10	10	10	10	10
Totals*** (Not including Secondary Roads)	55	55	75	125	130

*First deployment cycle only, not to be included in second and third cycles.

**Some crew served weapons are hand carried (e.g., the 90 mm recoilless rifle), and others are vehicle carried (e.g., the 106 mm recoilless carried during tactical deployment, as applicable. In other words, one case or the other will apply - not both.

***The total mileages given in this table are generally arbitrary. However, deviation should be avoided so that subsequent tests may be effectively compared.

The dust course mileages are subtracted from the total mileages, and the remainder is divided amont the world's principle desert terrain components according to the percentage of total world desert area that each component occupies.

2 Driving Courses

Two aspects of motor vehicle operation are of principal concern in respect to the desert. These are mobility (the ability of the vehicle to move about in the desert) and performance (the rate of movement). Mobility has to do with the terrain (tractive effort to climb slopes or push through sand and deep [illegible]) and suspension flexibility (to cross gullies and rocky fields). Performance, in contrast, represents factors related to the rate of [illegible] fuel consumption, excessive power losses caused by high temperature [illegible] intake air, [illegible] as well as degradation of components [illegible] such as [illegible] or even abraded paint.

Mobility evaluation requires both [illegible] country operation, but for purposes of repeatability and [illegible] vehicles, [illegible] over the same [illegible] and designated courses. This has been accomplished at YPG [illegible] as the sand slopes, [illegible] tank, level cross country, gravel and [illegible] courses [illegible] area.

By the same reasoning, specially [illegible] and facilities for measuring vehicle performance, such as the [illegible] course [illegible] courses, are required.

3 Storage and Exposure Sites

In the life-cycle of materiel [illegible] are recognized as integral elements that must be evaluated in terms of [illegible] environment. Relatively [illegible] other aspects of the life cycle. Sites [illegible], however, must [illegible] requirements in order to assure that the environment is completely representative. Once established, these storage and exposure sites should be utilized to the exclusion of alternates whenever possible because of microvariations in the YPG environment which can be significant.

Exposure [illegible] criteria for all types of materiel are based on [illegible] of degree hours above 90 F (32 C). Typically, for ammunition, [illegible] might be [illegible] 3780 F-hr (21 C) over 90 F (32 C). Alternatively, certain other types of materiel may [illegible] conditions, such as open, uncovered storage of [illegible] with a minimum of 45 days [illegible] temperatures above 100 F (38 C) for 5 hours per day (240 F-hours (133 C)). The criteria chosen will [illegible] for the type of materiel and the guidance set out in the appropriate Test Operations Procedure [illegible] materiel. Exposure sites may also involve criteria for presence or absence of dust generated by [illegible] traffic [illegible] might be experienced in and around supply points and for covered or uncovered storage, depending upon the conditions being simulated and the type of materiel [illegible] the expected environment [illegible]. A [illegible] specification for dust exposure states: "Vehicular traffic will be [illegible] of the storage area, with a [illegible] of 120 vehicles passing during the storage period (21 days) [illegible] deposits will be [illegible] on adjoining roa[illegible]

D TEST SUPPORT

Many aspects of the operations of a testing center such as YPG are those of administration and supply in support of the testing mission. Suffice it to state that such activities must be present and have adequate personnel and facilities to perform their tasks without delaying the technical objectives. Technical support of the testing mission, on the other hand, is a major and inherent element of that mission itself. Technical support includes all of those aspects of preparation, measurement, data transmission and recording, data analysis and reporting, without which the testing would be meaningless. Both fixed and portable instrumentation facilities are necessary. Fixed installations include data transmission and recording and computer terminals. portable facilities include instrumentation that is trailer-mounted, installed on materiel, or vehicle transported. An instrumentation laboratory charged with development, procurement, servicing, calibrating, maintaining, supplying and, on occasion, operating such instruments should be available.

Adjunct support of a computer staff, photographic laboratory, materials and chemical laboratory, and a technical library are also essential.

E. TEST PROCEDURES

A separate Test Operations Procedure (TOP) has been developed for each type of materiel, and this must be studied to determine the detailed requirements for any given item. Such test procedures delineate provisions to accommodate the life-cycle conditions expected for the type of test item concerned, and each procedure outlines specific data to be collected and tasks to be accomplished. In common, these procedures include provisions for the following:

- **Test Preparation.** Review what is to be tested, the data and information to be obtained, and facility and support requirements.

- **Recording Test Item.** Identifying the test item and ensuring availability of all operating and maintenance information and supporting supplies.

- **Inspection.** (Initial, and after each storage, transportation and operation phase)

  - *Test Item Readiness*—Assuring that the item is ready for test

  - *Test Item Changes*—Determining changes occurring in the item resulting from each test phase

- **Storage and Exposure.** To simulate forward depot, forward supply point, and operational field supply or storage

- **Transportation.** To simulate transportation to forward depot, forward supply point, and to and around the user domain (battle-field)

- **Functioning.** Placing the test item in operational configuration, with necessary performance measuring instrumentation, photography, and data recording systems installed; operating with appropriate controls and safeguards and recording all pertinent performance and environmental criteria

- **Safety.**

  - *Pre Test*—Ensuring, prior to operation and before and during each phase of the test cycle, that all safety statements and releases have been properly executed and that safety limitations are understood and observed by all personnel involved in the testing operation port includes all of those aspects of preparation, measurement, data transmission and recording, data analysis and reporting, without which the testing would be meaningless. Both fixed and portable *instrumentation* facilities are necessary. Fixed installations include data transmission and recording and computer terminals; portable facilities include instrumentation that is trailer-mounted, installed on materiel, or vehicle transported. An instrumentation laboratory charged with development, procurement, servicing, calibrating, maintaining, supplying and, on occasion, operating such instruments should be available.

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- **Transportation.** To simulate transportation to forward depot, forward supply point, and to and around the user domain (battle-field).
- **Functioning.** Placing the test item in operational configuration, with necessary performance measuring instrumentation, photography, and data recording systems installed; operating with appropriate controls and safeguards and recording all pertinent performance and environmental criteria.
- **Safety.**
  - *Pre-Test*—Ensuring, prior to operation and before and during each phase of the test cycle, that all safety statements and releases have been properly executed and that safety limitations are understood and observed by all personnel involved in the testing operation.

- *During Test*--Reviewing all aspects of the test materiel design and operation continually during all test operations for safety consideration.

- **Maintenance**. Establishing and executing procedures to observe and evaluate the effects of the environment on maintenance and servicing of the test item, its maintenance tools and supplies, and reporting of any maintenance and servicing deficiencies.

- **Human Factors**. Providing for recording of observations concerning human factor impacts, particularly those environmentally related to operation, maintenance, and handling of the test item.

- **Security**

    - *Evaluation Planning*--Reviewing procedures and techniques for observation and evaluation of signature effects of the test materiel in operation, transport or storage.

    - *Camouflage Materials*--Selecting appropriate camouflage materials.

    - *Camouflage Methods and Techniques*--Selecting methods and techniques of camouflaging the test materiel from ground and air observation.

    - *Security Evaluation*--Determining security from detection in each life cycle mode.

- **Test Planning**. In developing a test plan for a specific item, the test engineer must tailor the testing to the available (or obtainable) facilities with the objective of ensuring that the materiel will be properly and adequately evaluated in terms of its performance in the desert environment. If certain elements of the environment cannot be adequately imposed on the test item, these must be noted and discussed with respect to their omission or diminished effect in adequately evaluating the suitability of the item for its mission role.

F. THE TESTING PROCESS

The testing process consists of four essential steps: (1) test preparation, (2) test item preparation, (3) testing and data collection, and (4) analysis and reporting.

1. Test Preparation

a. *What is to be tested?* Review all instructional material concerning item and reports of prior tests of similar items, familiarize all personnel involved with reference material; arrange necessary training for test personnel.

b. *How will it be tested?*

(1) Time or project funding limitations, personnel limitations.

(2) Test reliability requirements and limitations.

(a) Sample size. Can test reliability be statistically assured?

(b) Alternative reliability assurance—Must reliability be inferred from engineering analysis of deficiencies rather than from statistical frequencies (e.g., testing of one tank as compared to 500 rounds of ammunition)?

(3) What ranges, driving courses, exposure sites are to be used—new facilities required?

(4) What data must be collected—instrumentation, technical photography required?

(5) Data analysis—How is data to be collected, recorded, reduced, analyzed—conputer requirements, data graphics needs?

(6) What maintenance, service and supplies are required?

(7) Support requirements—review needs and arrange for:

(a) Fuel and lubricant analyses

(b) Chemical and materials analyses

(c) Meteorological data—special requirements

(d) Computer support

(e) Graphics support—drafting, charting, illustrations

(f) Vehicle aircraft support

(g) Construction equipment support

(8) Personnel availability (test and support—professional and technician—orientation and training)

2. **Test Item Preparation**

a. *Identification, Marking and Recording*—to ensure identity of the test item(s) throughout all phases of the test program—may include photographs (Some portions of the identification process precede unpacking, but the process continues into the operating and inspection phases of the complete item and its component elements).

b. *Preliminary Inspection*—to ensure that all components are present and undamaged upon initial unpacking; record and report deficiencies with photographs or drawings as necessary.

c. *Detailed Inspection*—performed, as necessary, after phases of life-cycle testing, including operation, to determine effects of the prior test phase on the item and before any subsequent test might induce further deficiencies or adverse effects; record and report any deficiencies observed with photographs or drawings as necessary.

d. *Assembly* — assemble item or system into operational configuration, and make a *preliminary* check of its functioning; record and report any deficiencies. (Some portions of 1e may be involved prior to assembly.)

e. *Installation of Instrumentation* — certain data-gathering instrumentation or sensors may require installation in or on elements of the test item—e.g., thermocouples, strain gages, pressure sensors. An important premise must be observed, that the instrumentation must have no significant influence on the performance of the test item. Instrumentation may be required not only during the operational phase of testing but also during transportation and exposure phases while components or the entire test item are still in their "supply-packaged" configuration. Again, the instrumentation must not be deleterious to the test item—i.e., create packaging deficiencies.

3. **Testing and Data Collection**

a. *Storage Exposure and Transportation*

These aspects of the life-cycle simulation process are somewhat interrelated because they deal with the item in a more or less packaged configuration. Only in a few instances, when installed or stowed on an operational vehicle, aircraft or other equipment system, is an item transported in an unpackaged state prior to operational employment. Each type of item has been assigned specific exposure and transportation criteria in its respective Test Operations Procedure, which are to be considered as representative of specific phases of storage and transportation in its life cycle. These guides must be referred to in establishing the test plan for a specific item under consideration.

In all instances, inspection will precede and follow each subphase of the storage and transportation elements of the test cycle to ensure that deficiencies, induced during each subphase, are detected and noted in the record in relation to the conditions that precipitated them.

Specific sites and courses have been designated at YPG for storage and transportation of test material. For consistency in testing and correlation of results with previous tests of like items, such facilities should be used whenever possible. Only when special characteristics of design or operation of the test item demand it should alternative sites be utilized for these tasks. This is especially important insofar as the cross-country transportation cycles are concerned because of the possible major differences in the microenvironment that characterizes a specific course. It should be recognized that even a single, selected course varies from hour to hour during the day, as well as from day to day and seasonally. To impose further variation by use of alternative routes, even though in the same general area, only makes the problem of correlation of results more difficult.

b. *Functioning and Data Recording — Photographs*

All of the phases of the life cycle of deployment of a military item culminate in its operational use, and of all of the life cycle phases, this is the most distinctive. Test Operations Procedures have been prepared for the various major types and systems of materiel and, although generally consistent with respect to exposure and transport phases, are relatively distinctive and unique in their provisions for operational evaluations. Because the concerns are for performance evaluation, this area requires the most sophistication in data gathering systems—instrumentation of physical functioning; performance parameter measurements; data transmission and recording systems, possibly including hard-wire or radio telemetry—and specialized, complex instruments such as cinetheodolites, velocity coil arrays, and field dynamometers.

The specifics of functional tests of the equipment are to be found in the applicable Test Operations Procedure. It is essential that this, as well as test reports of earlier items of the same type, be closely studied to assist in preparation of the test plan and selection of appropriate test techniques, test ranges or courses, and instrumentation techniques.

The data reduction plan is also inherent in this phase and must be worked out in coordination with the computer facility, including possibly real-time data recording through a computer terminal, as well as data analysis from cinetheodolite and high-speed cinegraphic or video camera coverage and CRT displays of transient phenomena.

Photography of visually important or interesting aspects of the item in operation can be most valuable in describing its characteristics. It is most important that deficiencies, defects, or failures of components be visually portrayed, if possible, either by photographs, drawings, or sketches.

c. *Safety and Human Factors*

These aspects of testing are closely related and, although they are of some concern in the exposure and transport phase of the life-cycle, are, more importantly, matters for continual surveillance during operating phases of the equipment under test. Again, the primary concern here is to analyze the effects of the desert environment in these areas, even though deficiencies that might occur in other environments should not go unnoted.

Since "safety" is protection of op[illegible]ating or adjacent personnel from hazardous effects of the materiel and 'human factors' also relates to functioning of the equipment in conjunction with its operators or those around it, these factors must be kept in mind during all test phases. Appropriate surveys, check lists, and interviews with operating personnel should be developed prior to the initiation of testing and observations recorded by experienced specialists in these technical fields during all phases of the test program.

Areas of concern might be the effects of hot metal surfaces or sand and dust on the human operators' increased water needs; quicker onset of fatigue; higher ambient air temperatures; perspiration on hands (slipping on controls and tools); sunglare, lack of contrast of sunlit and shaded markings on controls; and increased workload necessary to keep equipment clean and operable.

d. *Maintenance*

Two aspects of maintenance of the test item in the desert environment are of primary concern:

(1) Are special or enhanced maintenance operations necessary to provide reliable performance in the desert as compared with normal operations?

(2) Does the desert environment have adverse effects on the maintenance process, tools, equipment, and materials used for maintenance of the test item?

Some general aspects of difficulty of maintaining equipment in the hot deserts are the constant presence of blowing sand and dust, presence of hot surfaces on equipment being serviced, tools becoming unbearably hot from lying on the hot ground or in the sun, and rapid fatigue of personnel. There are generally increased requirements for changing oil and air filters, adding coolants, replenishing evaporated liquids; and maintaining cleanliness inside and around controls, switches, and operating elements of the test item.

Each type of material is differently affected in this respect, and specific provisions for maintenance evaluation are provided for each in the Test Operations Procedures. The principal concern, however, is that all maintenance conducted on the test item be recorded. The record should provide comments and information as to whether maintenance actions are scheduled or unscheduled, the parts or components involved, the amount of time required, ease of accomplishing each task, necessity for special tools or skills, and adequacy of manuals and instructions, all with particular attention being given to the effects of the desert. The record should be completely clear with respect to the impact of the desert and, where practicable, supported by photographs or drawings illustrating any deficiencies observed.

e. *Security*

The desert environment, at most times, presents a difficult problem in preventing observation or detection of materiel by an enemy. Visibility is usually very good; ground cover is sparse; and only terrain irregularities --gulleys, dunes, hummocks or rocky hills--provide possibilities of natural concealment. Vehicle tracks in open terrain remain visible for long periods of time, and vehicle movements, artillery and rocket firing can raise dense clouds of dust that can be seen at long ranges.

Each Test Operations Procedure has specific provisions for testing feasibility of concealing each type of material from observation and detection, usually in a multiplicity of terrain types, such as open desert pavement with no cover; rocky or boulder-strewn desert floor with no cover; desert floor with non succulent xerophytic vegetation, surfaces composed of loose or drift sand.

Typical observation ranges of 500, 1000 and 3000 meters are used both at ground level and elevated positions, as well as from aircraft and at different times of the day and with various amounts of cloud cover.

Specific efforts are made to provide optimum camouflage for emplaced weapons, storage sites for supplies, and parked vehicles, utilizing equipment painting and camouflage net garnishing materials best suited to the desert terrain.

Observations are made and recorded with regard to signature effects during transport, emplacement and use of the equipment in relation to operational noise, dust clouds, flash, smoke, track patterns, EM radiation, and the like, as well as comments concerning static concealment. Photographic records of these tests should be an integral element of the analysis and report. Color and B/W still pictures, cinegraphic, and IR photography should be considered for inclusion in such coverage, depending on the type of item under study.

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APPENDIX
BRIEF HISTORY OF U.S. ARMY YUMA PROVING GROUND

A DEVELOPMENT OF WESTERN DESERT LANDS

Several factors bore upon establishment of a U.S. Army desert proving ground and, in particular, selection of the Yuma site for it. Obviously, available space and a hot desert environment were prerequisite; however, historic events were also influential. Early interest in development of western desert lands led to enactment by the Federal Government of various related statutes, among which was the Reclamation Act of 1902.[1,2] Initially, objectives were to encourage private development of irrigation projects and later to enable the Federal Government to participate in projects the [illegible] of which exceeded the capabilities of nongovernmental sources or of individual states or groups of states. Participation by the Federal Government was necessitated also to assist in resolution of conflicting water rights interests of affected individual states or of the United States and its neighbors. Still another factor was the advent of World War II, especially the type and scope of warfare in North Africa in which United States armed forces became directly involved beginning in November 1942.[3] Responsibilities with regard to ground and surface water resources in the desert west had resulted in important activities in that area by the U.S. Army Corps of Engineers preceding that time and during later operations there.

Construction of Laguna Dam on the Colorado River, [illegible] miles upstream from Yuma, was initially undertaken privately in July 1905 to impound water for irrigating the Imperial Valley in California and areas near Yuma. Its completion was assumed by the U.S. Bureau of Reclamation when the original contract was defaulted because of cost overruns and construction delays. These were due in large part to unusually heavy rains in 1905 and 1906, which resulted in diversion of the total flow of the Colorado River into the Salton Trough, reforming the Salton Sea[1] and deepening the river channel at the dam site because of the scouring action of flood waters.[3] Construction was finally completed in March 1909.[3,4,5]

Imperial Diversion Dam on the Colorado, 17 miles above Yuma, and Parker Dam, farther upstream near Parker, Arizona, were both part of the Boulder Canyon Project undertaken after studies by the Bureau of Reclamation and the Corps of Engineers.[3] Both are multi-purpose dams: flood control, reclamation, and hydroelectric power generation. Lake Havasu, above Parker Dam, completed by the Bureau in 1938,[3] also feeds the water supply systems of Los Angeles and other southern California cities.[3,6] Imperial Dam, begun in 1936 and completed in 1939, also by the Bureau,[3,5] incorporates features to provide desilted water to the Imperial and Coachella Valley irrigation systems via the All American Canal and to the Gila River Valley via the Gila Canal.[4] Following its completion, Laguna Dam was maintained as a control for the Imperial Dam tailwater.[1]

Dam construction and subsequent operational maintenance requirements resulted in establishment of certain facilities at the dam sites, particularly construction of semi permanent facilities at Imperial Dam.

B. WORLD WAR II PREPARATORY ACTIVITIES

Subsequent to reduction of activity following completion of Imperial Dam, United States eventual involvement in the war in Europe as a combatant became increasingly evident. United States mobilization for World War II and reports of equipment failures in North Africa due to effects of that environment stressed needs for materiel testing and troop training in the desert. Prior to commitment of the United States forces to combat in North Africa, the U.S. Army Desert Training Command was established and conducted troop training exercises in the Desert Maneuver areas in California's Mojave Desert and in southwestern Arizona including areas now occupied by Yuma Proving Ground. Field trials of equipment were conducted, including operations with troops, but no permanent test sites were established. Service tests and equipment evaluation in connection with maneuvers were directed by various special boards grouped under the designation Desert Test Board, headquartered at Barstow.

Concurrently with troop training exercises, the Desert Test Branch of the Engineer Board, Fort Belvoir, Virginia, made studies of subsurface water resources in the Desert Maneuver areas in 1942 and 1943. The area covered was extensive, including along its perimeter such localities in California as Indio, Twenty Nine Palms, and all of Imperial County north of the Southern Pacific Railroad to El Centro, as well as El Centro itself; Jean and Searchlight, Nevada, and Kingman, Alamo Dam and Lake on the Bill Williams River, Arizona, along the north edge of KOFA Game Refuge, in La Posa Plain, and along the Gila River from Texas Hill to Yuma. Drilling records and logs of water wells on private property, along railroads, in and around municipalities, and test wells sunk by the Engineers, plus water analyses provided information concerning availability and quality of water and, to a limited extent, sub-surface soil composition and structure. Little information of this type was obtained for what is now the Proving Ground area proper.

Except for service tests performed during desert training maneuvers, Corps of Engineers equipment was evaluated by the Corps of Engineers, Yuma Test Branch, directed from Fort Belvoir, Virginia. Evaluation of engineer construction and bridging equipment was conducted on the Colorado River below Imperial Dam. During 1942, leased buildings were used during test work conducted near Laguna Dam. The lack of close by facilities resulted in a move to the Imperial Dam vicinity in January 1943 and probably the first Army use for engineering test purposes of the area now contained within Yuma Proving Ground. The Engineer Board tested motor graders in the construction of desert roads, four wheel drive and tandem-drive graders in sand, "V" drags, and various tractors at Yuma and did comparative testing of dozers and graders at Yuma and at Camp Young and Thermal, California. The Desert Training Command conducted complementary service tests at Camp Young. Laguna Army Airfield was constructed in its present location during this period.

From its initial establishment and designation as Yuma Test Branch, through 1949, the area underwent several name changes within the Corps of Engineers, becoming Yuma Test Station 1 January 1949 and being declared excess to Army requirements effective 1 January 1950.

C. YUMA SITE SELECTION

During 1950, a team representing the Army Technical Services—Ordnance Corps, Signal Corps, Quartermaster Corps, Chemical Corps, Transportation Corps, and Corps of Engineers—headed by a representative of the Army Office of Research and Development, Dr. Paul Siple, toured the southwestern desert area to evaluate the suitability of various areas and recommend a site for establishment of an Army desert test facility. The areas examined included the former Yuma Test Station and surroundings, Blythe and areas around Barstow, California, and those such as now occupied by Fort Irwin, Edwards Air Force Base, Twenty-Nine Palms Marine Corps Base, and south west toward Indio, El Centro, and the Coachella Valley area. The evaluating team recommended the Yuma area for establishment of the Army desert test facility not only because of environmental suitability and available space but also because of the existence of administrative, laboratory, and military housing facilities and utilities constructed by previous Corps of Engineer occupants.[10] It was reestablished as a test site and Class I installation in the spring of 1951 under administrative control of the Sixth Army.

D. EARLY FORMAL TEST ACTIVITIES

1. Corps of Engineers

The Engineer Research and Development Center at Ft. Belvoir reestablished a permanent test team at Yuma Test Station in the spring of 1951. This team, designated the Corps of Engineers Climatic Field Test Team, continued previous investigations in the area, conducted desert tests of construction equipment, and provided scientific support to various users and tenant activities. This effort continued until the Army reorganization of 1962, by which time the team was known as the Corps of Engineers Desert Test Activity.

2. Ordnance Corps

The first Ordnance Corps desert test programs at Yuma Test Station were conducted in 1951 and 1952 by the Ordnance Climatic Test Detachment, which operated in the summer at Yuma and in the winter at Ft. Churchill, Canada. By 1960, its mission had been expanded to include development testing of free-flight, short-range rockets; testing of fuels and lubricants; and conducting studies of air-drop effects on Ordnance materiel in the air delivery program.

3. Quartermaster Corps

The Quartermaster Research and Engineering Command of Natick Laboratories, Massachusetts, sent teams to Yuma Test Station starting with the summer of 1953. A small Quartermaster detachment was permanently stationed at Yuma, operating a petroleum laboratory for the Ordnance Test Activity, but test teams usually stayed for just a portion of the summer. The Quartermaster activity for testing air delivery systems, methods, and techniques was transferred from Ft. Lee Blackstone Army Airfield, Virginia, to Yuma in 1958; however, this was not essentially an environmental test activity.

4. Chemical Corps

The Chemical Corps transferred a small party to Yuma for environmental tests in 1952. Facilities, including a toxic chemical laboratory were built for environmental and surveillance tests of agents and protective equipment. Subsequently, responsibility for the activity was transferred from Edgewood Arsenal to Dugway Proving Ground, and the work was reduced to surveillance testing of nontoxic chemical weapons and desert environmental tests of protective equipment.

5. Signal Corps

The Signal Corps provided a permanent meteorological detachment beginning in 1951. Test teams utilized the Test Station for at least the summers of 1951-53, concerning primarily desert environmental tests of radio and landline carrier equipment and shelters. In the late 1950's, the Electronic Proving Ground, which had been established at Fort Huachuca, instituted a program of test flights of surveillance drone aircraft from Yuma Test Station to Ft. Huachuca, utilizing, in part, the station's airspace. A permanent party, the Surveillance Drone Test Detachment, was formed at Yuma in 1959.

E. PERTINENT ESTABLISHMENT OF YUMA PROVING GROUND

Following the reorganization of the Army in 1962 and the dissolution of the Technical Services, the Yuma Test Station was redesignated Yuma Proving Ground, effective 1 July 1963, under the Army Material Command (Test and Evaluation Command) and as a major DoD range test facility managed by the Department of the Army, 16 August 1971.

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